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One way to approach an answer is to collect related viewpoints into easily understood classes. Many classifications are possible. A six-category scheme has frequently been used and seems reasonable.[4]

Imagine management as a cube. The six faces of the cube shown in Figure 1-1 are just different ways of viewing the same subject. Researchers have explored each of the six profiles in depth, and each group typically insists that its view is the most meaningful. One of these profiles may indeed be *the* way to best understand and practice management, but no one has ever come up with an Emmy award to recognize it. On the other hand, it is doubtful if just one viewpoint should be the single source of management theory, since managers throughout the world find themselves operating in a widely varied range of situations calling for many different methods of operation.

Examining the different faces of management can serve two purposes. (1) If you study the historical evolution of management, you realize the depth and breadth of this subject. (2) Fundamental concepts emerge from the study, and these are the very foundation material from which we draw the applied skills of management. You will find all the faces [illegible] management briefly reviewed in the following sections, and each face is illustrated with a sketch of a related management tool.

### Scientific Management

The theories and practices originated by a group of management innovators in this country in the years from 1880 to 1920 have become known as *scientific management*. This almost descriptive name reflects the emphasis placed on formal methods used in investigations of work patterns. The investigators, mostly engineers, were interested in improving labor efficiency. Their combined contributions established procedures for (1) identifying the work methods that produce the "one best way" to complete a task, (2) developing time and motion studies as means to set a standard time for a task, and (3) determining a fair and potentially motivating wage to award completion of the task.

Frederick Taylor was the leading advocate of the early movement. His output improving methods in metal cutting, shoveling, and pig iron handling were eye openers. In addition to suggesting better ways to perform and pay for physical work, he proposed ways to improve supervision through specialization. Underlying all his recommendations was the plea for industry and government to apply more systematic analyses to shop operations.

Associates and followers of Taylor complemented his ideas. Henry L. Gantt developed task and bonus wage systems and contributed charting techniques

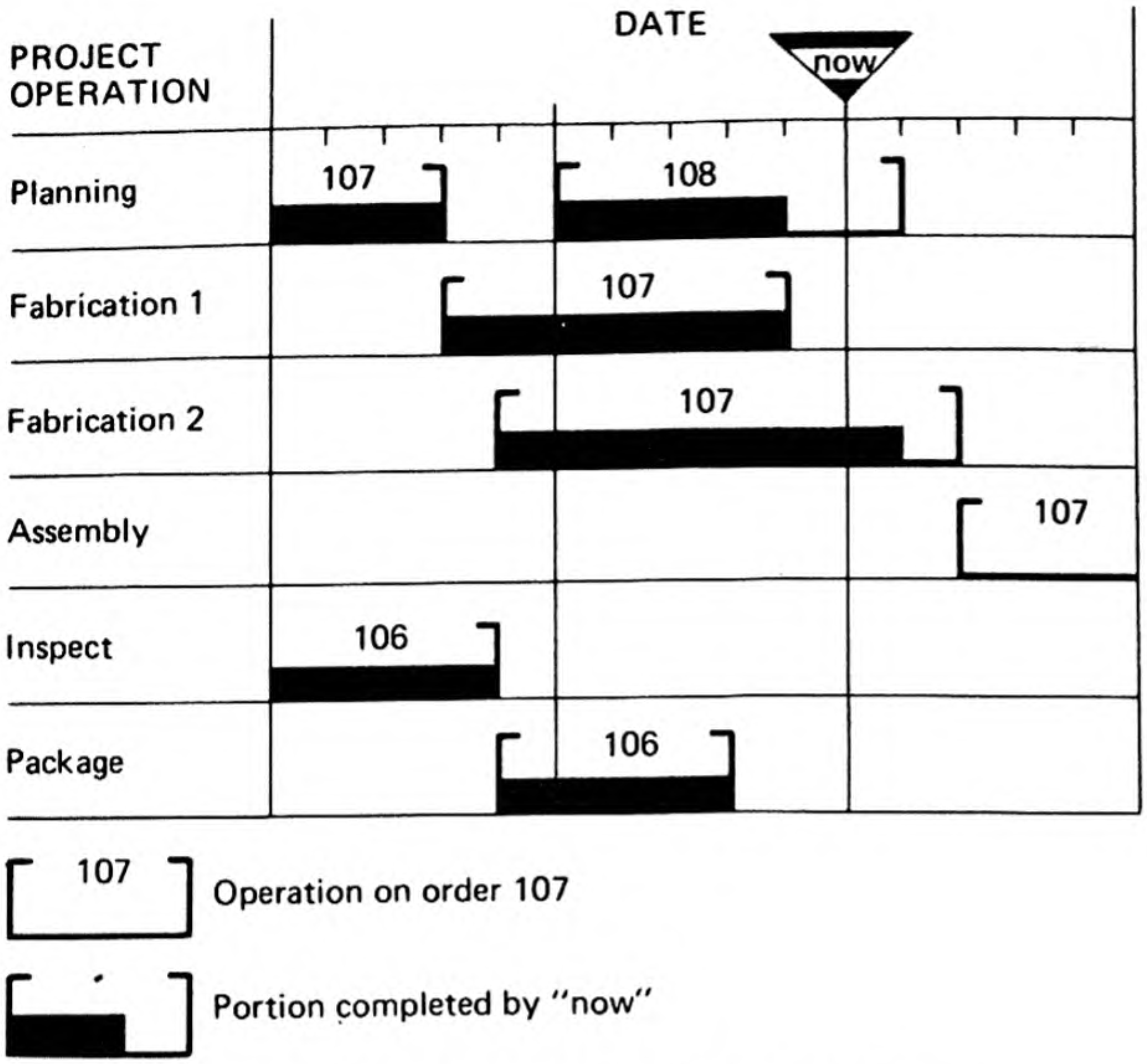


*Fig. 1-2. Gantt charting for production scheduling.*

for sequencing operations. Gantt charts, shown in Figure 1-2, are still widely used for production control. The team of Frank and Lillian Gilbreth refined motion study by classifying hand and arm movements as independent components combined to do a specific task. They identified 17 categories such as "search," "grasp," "position," and "hold." In 1910 Harrington Emerson made an impressive appearance as an expert witness before the Interstate Commerce Commission by testifying that the railroads could avoid a rate increase if they would apply scientific management principles to save one million dollars a day; and in 1910 a million dollars was a lot of money!

In spite of the recognition given to its founders, scientific management was never completely accepted. People criticized its basic approach as being too mechanistic, although it conformed to the popular opinion that scientific methods could discover and explain most truths of nature. Many of the stopwatch and incentive features favored by Taylor ran counter to the goals of the young and lusty union movement. You hear the same complaints from unions today. Although the early effect of scientific management was muted, its influence has been lasting.

One of the oldest *visual* planning methods was originated by Henry R. Gantt in 1917. He introduced several types of diagrams for production control and ge-scale procurement scheduling. Figure 1-2 is quite standard for hand-drawn a[illegible] still being used in industry.

ical Gantt chart shows the planned sequence of several activities which are g on at the same time. Activities are on the left or vertical axis, and their sequences are horizontal bars, plotted along a time scale which corresponds a calendar. Actual accomplishment can be compared with that planned by [illegible] marking the chart.

more complex projects, management specialists are now using other chart- techniques such as critical-path networks. A computer can produce bar charts more quickly and accurately than a manual charter. However, for many [illegible] operations, the Gantt chart is still used as it was more than 50 years ago. This method is a tough, durable one which has stood the test of time!

**Management Processes**

The concepts called *management processes* were mined from the same vein that yielded scientific management. Both schools of thought were based on an analytical evaluation of ongoing industrial experience. Their difference stems from the level of operations receiving attention. The focus of management processes is centered on the organization of an enterprise and the functions of its managers.

Henri Fayol[5] drew upon his experiences as managing director of a large coal mining company to theorize about general principles to guide the thinking of managers and about the basic functions of management. His principles ranged from abstract conceptions of group discipline and individual initiative to specific directions for specialization of labor and compensation to reward work. Fayol's five functions of management were planning, organizing, commanding, coordinating, and controlling. These functions set forth his version of what management was supposed to do, and his principles were guides to get it done.

The functions and principles described by Fayol served as springboards for more compact yet more complete theories to relate management processes to the conduct of business. Among the prominent writers who advanced the study of organization and organizations were Lyndall Urwick[6] and James D. Mooney.[7] The collective views of these authors and others are often praised as beginning *classical organization theory*, a management perspective which emphasizes structure, administration, and formal relationships. On other occasions the same views are criticized for not giving enough recognition to the effect of human behavior on management processes. While maintaining the continuing value of classical organization theory, Urwick also recognized the art of management when he wrote:

> The simple fact is that managing is, as is medicine, a practical art. Like medicine it depends on a wide range of underlying sciences from anatomy to zoology. Again like medicine, no laboratory experiments or theoretical formulations are of use to practitioners till they have been tried in the fire of 'clinical experience.'[8]

Two of Henri Fayol's principles dealt with *unity of command* and *chain of command*. The principle of unity of command states that each employee can have only one supervisor. The principle of chain of command establishes orderly communication links between the levels of command. Military organizations, through history, have used both principles rigidly.

Few people would argue that having to answer to two bosses at the same time is a comfortable position. However, if you stick to a one-boss-per-man format, you can only communicate to a single level above and below each position. Recognizing this communication problem, Fayol proposed that the up-down reporting chain be kept intact, but that peers, or equals, be allowed to communicate.

This is called *lateral communication* and is illustrated by Fayol's "bridge" in Figure 1-3. The solid lines represent the chain of authority and its channels of information flow. Note that the boxes at each level bear labels made up of standard industrial titles of rank. Together, these lines of authority and the nameplates in the boxes form an organization chart. However, the dashed arrows indicate peers who are empowered to exchange information whenever the levels above give their permission. Without a bridge, a message from foreman to foreman theoretically would have to pass at least through the supervisors.

Rigid communication channels seldom exist in modern organizations. If the current talk links of many business concerns were plotted on the concern's formal organization chart, it would look like a cobweb. While such bridges are easy to erect and are often built without permission from above, it is worth remembering that the bridges do not really change the established lines of responsibility and authority.

### Human Behavior

The *man* in *man*agement began to receive special attention after publication of an extensive study of production and working conditions at the Hawthorne

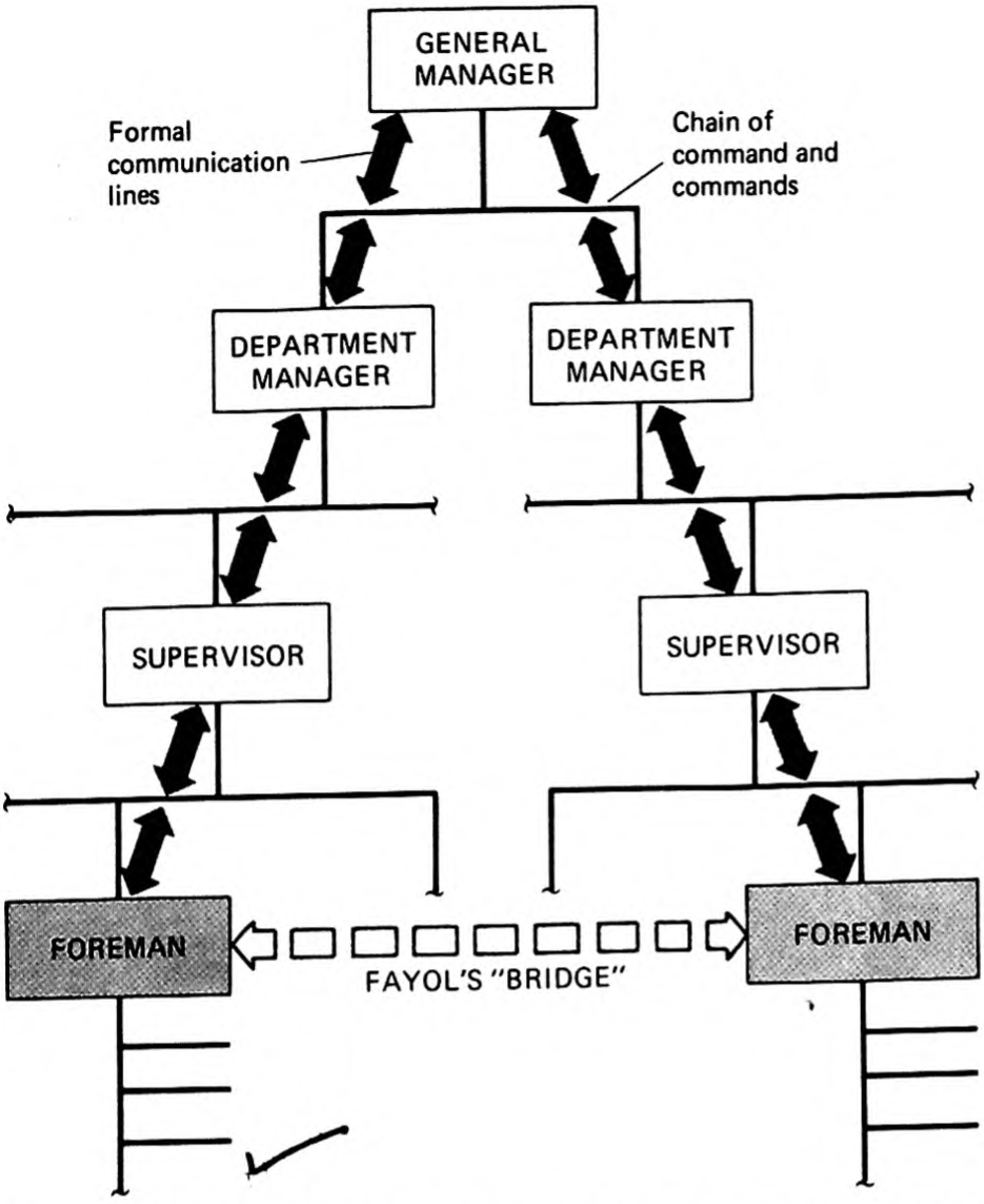

GENERAL MANAGER
Formal communication lines
Chain of command and commands
DEPARTMENT MANAGER
DEPARTMENT MANAGER
SUPERVISOR
SUPERVISOR
FOREMAN
FOREMAN
FAYOL'S "BRIDGE"

*Fig. 1-3. Fragment of an organization chart illustrating formal and abridged communication lines.*

Plant of Western Electric Company.[9] From 1927 to 1932 researchers from Harvard University observed the reactions of workers as various features of their work environment were changed. These variations were carefully controlled, and the reactions were carefully charted. In one experiment, the intensity of lighting at the work place was increased for one group of workers, while it was held constant for another group—both doing the same work. Both groups increased their work output. The experimenters decided to continue this procedure, keeping the control group constant, while lighting for the experimental group was decreased. Production continued to advance for both groups. Finally, they reduced the lighting of the experimental group to the level of moonlight and production finally declined.

It was evident that factors other than illumination were at work here. Apparently, these people were affected by the concept that someone cared about their working light and was doing some study upon the subject. Thus did another dimension of management study, human behavior, enter the scene, and researchers began to search for basic factors in the way people relate to each other.

When management began to consider human relations beyond such economic concerns as pay and profit, they got into such areas as motivation, leadership, morale, attitudes, and other aspects of personal or group interaction. Much writing has been done on these topics, but so uncertain is human nature that some management practitioners wonder what to believe. Can the recommendations of human relations specialists be relied upon to solve daily "people problems"? The question of how to serve man in management is still vital.

*Motivation* is defined as an inner urge that prompts a person to act in a certain way. Certainly a manager wants to motivate productively everyone working for him. The problem with motivation is that you can't see it, feel it, or measure it. Even though you may recognize it from the good effects it produces, you cannot be sure you will always find the secret of *every* person's motivation. Motivation is an individual matter, a force which seems to respond to many influences which are beyond control.

Early writers spoke about money as the prime motivator. We still consider wages to be of prime importance in the motivation process, but they are not the only

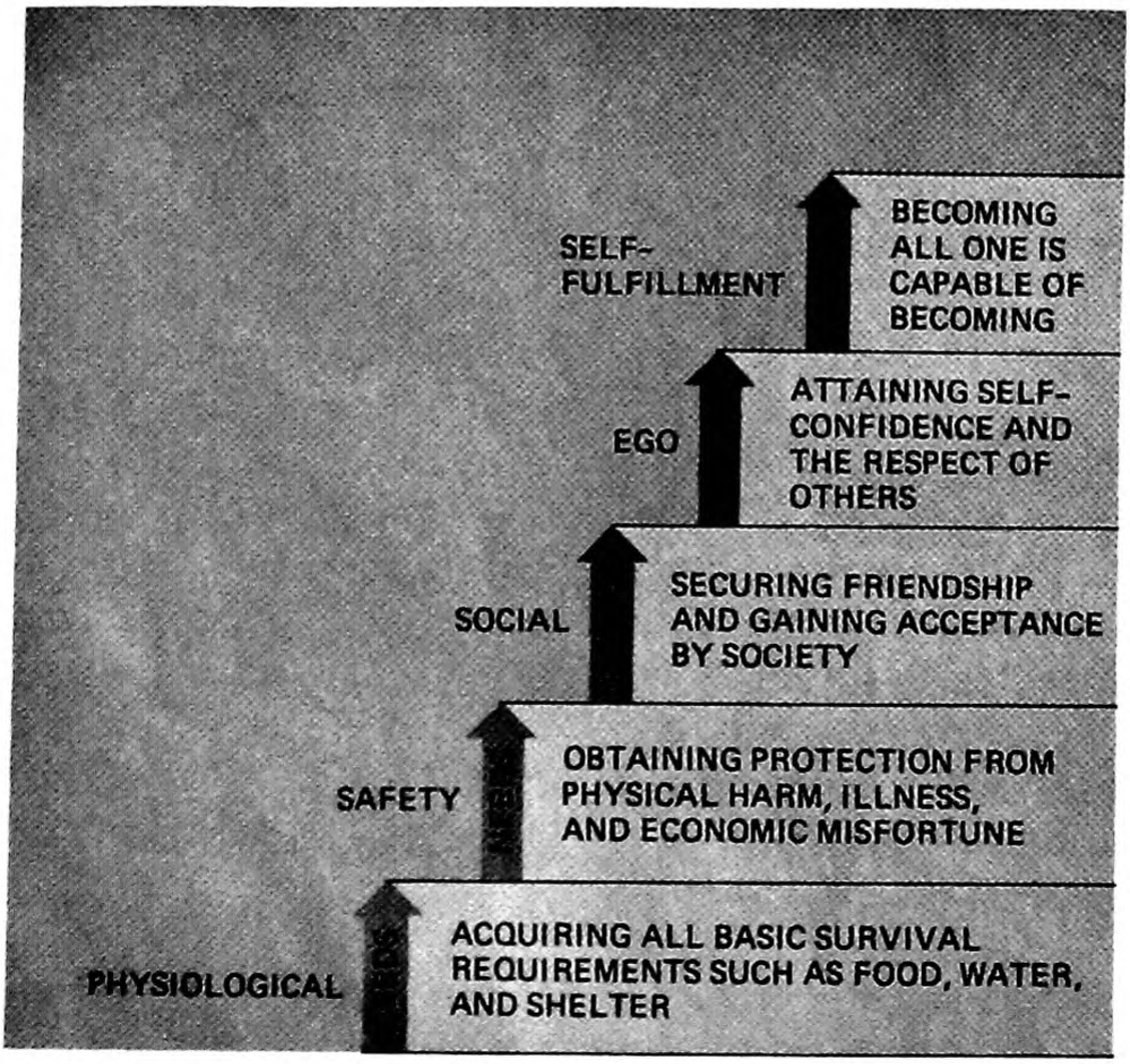

SELF-FULFILLMENT
BECOMING ALL ONE IS CAPABLE OF BECOMING
EGO
ATTAINING SELF-CONFIDENCE AND THE RESPECT OF OTHERS
SOCIAL
SECURING FRIENDSHIP AND GAINING ACCEPTANCE BY SOCIETY
SAFETY
OBTAINING PROTECTION FROM PHYSICAL HARM, ILLNESS, AND ECONOMIC MISFORTUNE
PHYSIOLOGICAL
ACQUIRING ALL BASIC SURVIVAL REQUIREMENTS SUCH AS FOOD, WATER, AND SHELTER

*Fig. 1-4. Factors affecting motivation.*

factors. A. H. Maslow developed a ladder of needs, based upon the premise that man continues to want things even after he has satisfied earlier wants. A version of this ladder is shown in Figure 1-4.[10]

Here motivation is pictured as an ordered series of satisfaction levels. You will notice that the first two levels are physical, while the last three are mental. According to the theory, humans are motivated by wants from the next level yet unsatisfied. They continue to have wants from birth to death, so long as rational hope remains.

The ladder of needs reveals many clues for managerial pursuits. Modish one-word slogans such as participation, consultation, opportunity, or security have to be evaluated in reference to particular individuals, distinct work groups, unique company conditions, and applicable social mores. Actions may take the form of merit awards, improved safety programs, promotion opportunities, special recognition, and more open communications. The role of management is to locate any dissatisfiers and to find practical means to replace them with satisfiers, a difficult role to play because the actors and the stage keep changing.

### Social and Economic Systems

Vilfredo Pareto, an Italian economist and sociologist, is perhaps the spiritual sire of the movement to view organizations as complex socioeconomic entities. This view merges three images: the organization and society, the organization and the community, and relationships within the organization. With such a broad scope to consider, the study of an organization becomes the study of a system.

A chain of questions that guides system studies goes: (1) What are the key parts of the system? (2) How are they interdependent? (3) What processes in the system ease the adjustments of parts to each other? (4) What are the goals of the system? Chester I. Barnard, at one time president of the New Jersey Bell Telephone Company, treated employee relationships from a system framework when he proposed that the function of an executive include (1) maintenance of communications by stressing "understandable" messages between workers and managers, (2) setting forth clearly what work is to be done by whom, (3) establishing cooperative relationships where employees can weigh the inducements for work against the effort required, and (4) stating objectives in terms of required resources and cooperative effort.[11] Barnard's notable premise was the importance of a functioning system of communications within an organization.

Elementary economics were undoubtedly a concern of businessmen even in the long gone days of bartering. As money became the dominant medium of exchange, businessmen developed more complex financial strategies. Increased government planning, especially that triggered during the depression years of the 1930s, prompted related economic planning in industry. Planning provoked analysis. Economists and accountants examined internal and external cost-profit relationships of organizations. Significant findings led to the recognition of *managerial economics* as a special field of inquiry.

Many of the methods of economic analysis are simply procedures to encourage managers to take an overview of operations. Particularly in smaller enterprises it is easy to become so enmeshed in day-to-day problems that little time is left to observe how these operations contribute to the total economic health of the organization. The following example of sales-dollar analysis describes an elementary method of studying operations, yet it provides a broad view of the way operations are related and support each other.

Sales-dollar analysis is an aid to economic studies developed in the early 1900s. The analysis is a quick and easy method of highlighting the ratio of sales to cost and profit for management's attention. Two versions are portrayed in Figure 1-5. The graphic representations are especially useful in explaining a current situation while you are endeavoring to decide upon corrective action.

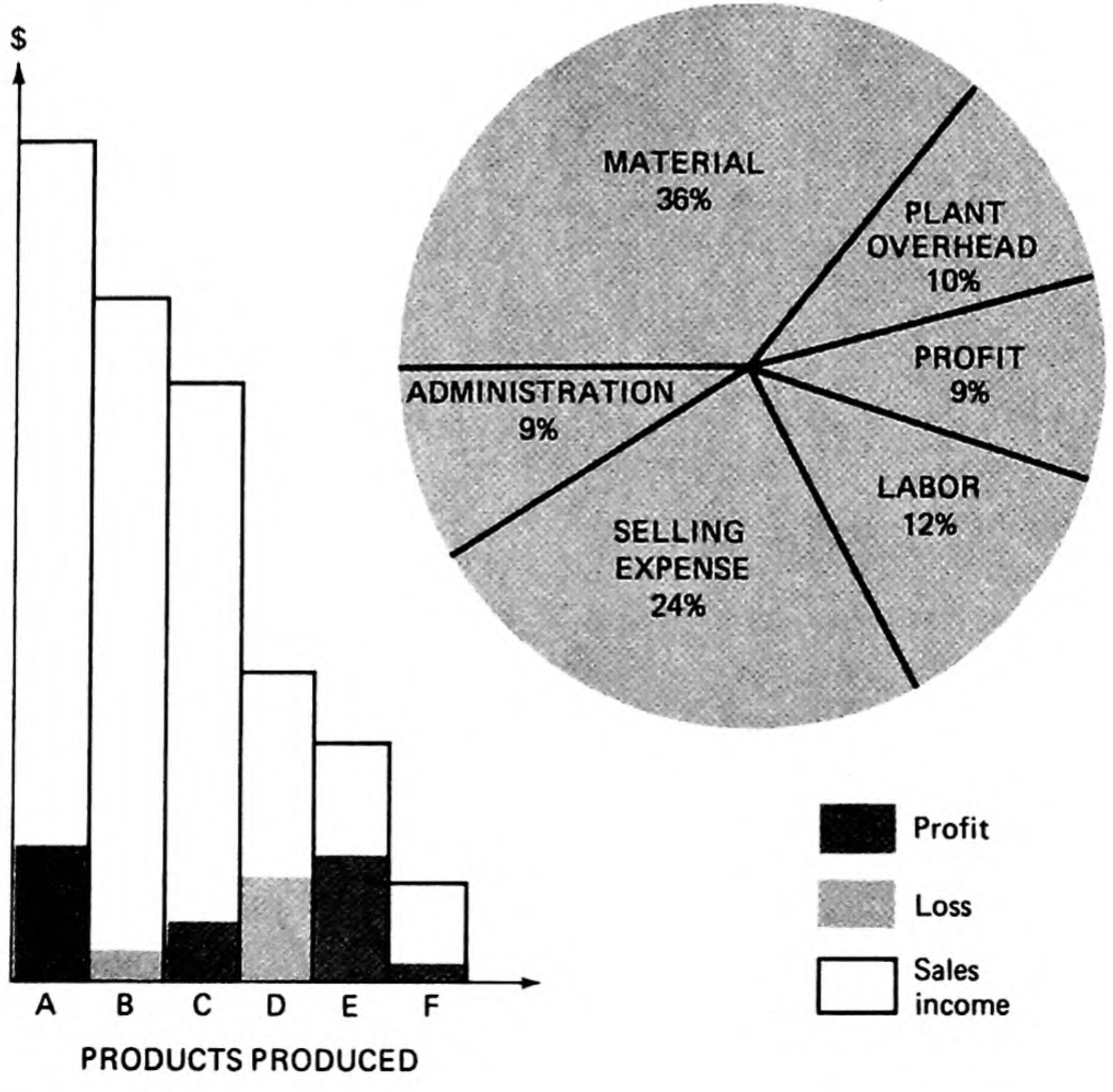


*Fig. 1-5. Sales-dollar charts.*

The pie chart in the upper part of Figure 1-5 shows what proportion of each dollar has been allocated to each cost and profit category. In the illustration, the major outlay for materials of the manufacturing plant is 36 percent of the total, and is the major item. It would therefore appear logical that you could contribute more to a successful cost-reduction program by attacking material expenses than you could by working on another cost segment of the total picture. This logic assumes that you could effect equivalent reductions in both segments. Consequently, economy drives are often aimed at the areas of larger magnitude. The problem is, however, that this kind of target may be a deceptive one. The company cannot always control material prices, since they often are set wholly by market conditions. Therefore, the most devoted cost attack might not make a substantial dent in the total outlay for procurement.

Sales-dollar analysis also produces interesting historical comparisons. A gradual change in an expense category, say administration, might not be evident until a chronological series of pie slices are contrasted. Without a check on creeping costs, it is easy for tiny slippages to accumulate until the load becomes suddenly alarming. Similarly, a comparison of the budgeted sales-dollar composition with the actual year-end sales-dollar pie spotlights costs that are out of line.

The vertical bar chart at the bottom of Figure 1-5 conspicuously points out which products contribute most to profit. Each bar shows the proportion of profit or loss per sales-dollar grossed by the product. Products B and D appear to be in trouble. Product E looks like a "comer" owing to its high profit to sales ratio. But even with the most detailed sales-dollar pie to help us, we have to guard against a one-shot interpretation. Perhaps product B is in the development stage where a loss was expected and its small penalty ratio might even be considered encouraging. Maybe product E got its handsome ratio by a freak fad or a temporary loss of competition. Again, a comparison of a series of dated charts is much more enlightening than an interpretation of one chart.

### Decision Theory

Concentrating on the theme of decision making may seem like a narrow view of management, but decisions are essential to any enterprise. An arbitrary division of decision theory into three subsets partially reveals its scope.

1. Investigations of value systems used by individuals and organizations in arriving at decisions.
2. Development of ways to include risk and other intangible factors in the decision process.
3. Examination of the information flow to and from decision centers and studies of the ways the information is acted upon.

Investigations launched into any of the above three areas soon reveal the internal workings that link different parts of an organization. Decisions made in one part affect other parts of the organization, and the data upon which decisions are made come from many sources in the organizational system.

Ever since people quit relying on instincts alone to make decisions, they have probably been telling each other how they did it. Jeremy Bentham, in his book *Principles of Morals,* published in 1789, maintained that managers should strive to do "the greatest good for the greatest number." He also proposed means to measure how good was "good." His contributions are interesting, but we still have no exact means to measure qualities such as beauty, reputation, enthusiasm, and other human values.[12] Efforts to develop measures for these intangibles have continued with the introduction of modern *utility theory* by von Neuman and Morgenstern.[13] This approach attempts to rate the utility or usefulness of an objective. Many qualities still defy measurements of utility but even an awareness of the role played by these qualities contributes to better decision making.

Conditions that are easy to measure still have to be interpreted and evaluated in the process of making decisions. It is not enough to have a huge collection of facts. You have to digest the data and manipulate figures to discover how the information applies to current and future decisions. Statistical theory, as developed by Abraham Wald, is the foundation for the science of decision making under conditions of uncertainty.[14] Most decisions involve some risk; no one can foretell exactly what will occur in the future. Statistical decision theory allows inferences about future behavior to be drawn from the pattern of past events.

The "chance" nature of events has fascinated thinkers for centuries. Mathematicians in the 1600s were interested in probability theory as it applied to gambling. In the next century they concluded that probability calculations could be used for advice on subjects less frivolous than games of chance. The subject then remained largely academic for more than another century until it emerged as a tool for production and quality control. Practical applications are now everyday occurrences in the conduct of business, ranging from shop-level checks of probability tables to boardroom strategy based on elegant research into probable futures.

The remarkable data-handling ability of computers has impelled examination of how information leads to actions. Psychologists have studied individual and group decision-making processes to come up with suggestions for improved communications and ways to seek consensus. Mathematicians, led by Norbert Wiener, have uncovered the basic relationships involved in system communications and control; this promising science is called *cybernetics.*[15] Other researchers developed the field of *information theory* (the study of the content of messages). Ideas from these infant disciplines are fascinating but little of practical value to managers has come from them.

A useful way to describe a manager is to call him a decision maker. He certainly must have many other talents, but his success in applying these talents depends quite heavily upon his decision-making ability. Most of his decisions are easy, almost automatic. A few are critical; at least, they seem vital at the moment of verdict. For these occasions he needs a tool more powerful than intuition to assist him. A decision tree is such a tool.

Decision trees, like decisions, come in many sizes and shapes. A modest version is shown in Figure 1-6. Graphic portrayals of decisions are most useful when you have many factors to consider. Then the graph helps clarify choices, aids evaluations, and acts as a vehicle for discussion or presentation. Drawing a tree for the example shown is of doubtful value owing to the few choices available, but it illustrates the potential.

The decision depicted in Figure 1-6 is whether to invest $100,000 in land or in bonds. These two alternatives are indicated by dashed lines radiating from

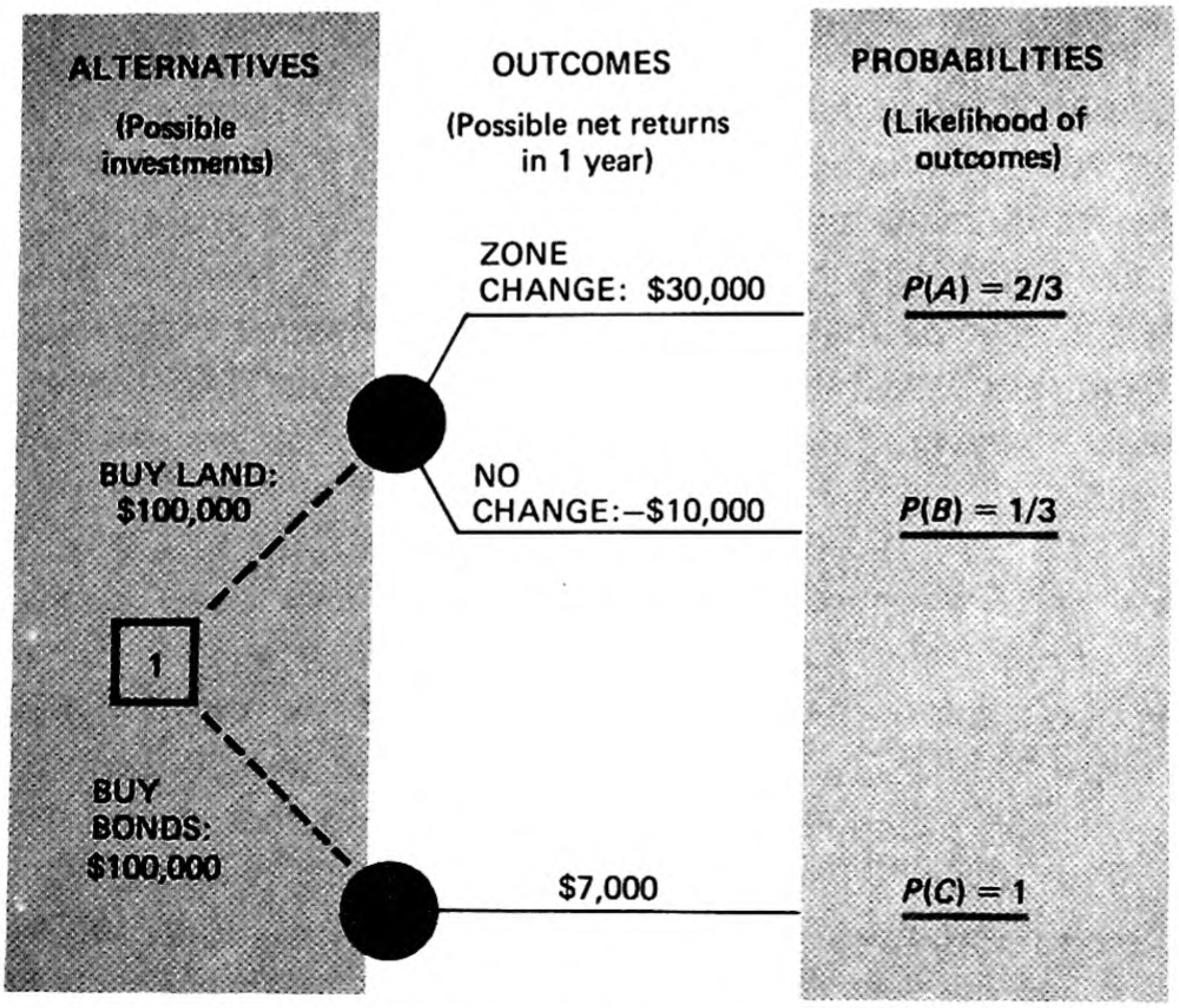

ALTERNATIVES
(Possible investments)
OUTCOMES
(Possible net returns in 1 year)
PROBABILITIES
(Likelihood of outcomes)
ZONE CHANGE: $30,000
P(A) = 2/3
BUY LAND: $100,000
NO CHANGE:–$10,000
P(B) = 1/3
1
BUY BONDS: $100,000
$7,000
P(C) = 1

*Fig. 1-6. Decision tree representing a choice between two alternatives, one with an uncertain outcome.*

decision square 1 (a chain of decisions stretching forward in time would be shown by a succession of squares). The lower branch (C) of the tree represents the option to buy bonds where the return of $7,000 is certain to be earned; its probability is $P(C) = 1$. There are two possible outcomes for the top branch; the land purchase has two chances in three, $P(A) = \frac{2}{3}$, of gaining $30,000 (A) or one chance in three, $P(B) = \frac{1}{3}$, of losing $10,000 (B).

From the outlined prospects it is apparent the decision maker must choose between a certain but relatively small gain or gamble for a much larger gain with the chance he will incur a substantial loss. Decision theory is a source of advice for his verdict (see Chapter 13). But even without formal theories, the decision tree suggests solution possibilities. Would a $10,000 loss be unbearable? If so, buying bonds is the answer. Maybe this tree should have more branches; one of the overlooked additions might be the most attractive. Perhaps the land-purchasing procedures should be investigated more closely to see if the estimated likelihood or magnitude of loss from the "no zone change" could be reduced. Are there any side effects such as goodwill that should be included along with the money values of the outcomes? Such questions need to be asked about significant decisions; a decision tree acts as a reminder.

### Management Science

Judging from the number of printed words and the volume of speeches devoted to it, management science must be "in." Since its hazy beginning about three decades ago, it has dominated management thinking. You can find its followers and promoters in many professional disciplines and at most organizational levels. Those who belittle it, though they are fewer in number, also are widespread. People criticize management science techniques mostly on the basis that they have promised more than they have delivered. These techniques are so popular, however, that they are assured a spot in the limelight for years to come.

Management science came from many sources. You will find many of the modern refinements come from theories proposed centuries ago. In 1716 Thomas Watts wrote about the importance of measurement and mathematics to businessmen. Charles Babbage worked unsuccessfully for over 30 years to build a workable automatic computing machine. But during that period he published a book (1832) which stressed the value of carefully collected data as the basis for making decisions. Also in the nineteenth century, Walter Shewhart, in his work with the Bell Telephone Laboratories, called attention to the use of probability theory and statistics for managerial decisions and control policies. The main contributions to management science, however, came from interdisciplinary cooperation attempted as an expedient during World War II.

Scientists from many fields were recruited to help solve wartime problems of troop movements, sea and air defense, and supply strategies. The collaboration produced excellent solutions in spite of the fact that the scientists previously had little or no exposure to the military and civilian problems addressed to them. Their success was attributed to knowledge and methodology borrowed from their scientific endeavors to attack analogous problem situations. This approach was called *operational research* in Britain and is now known as *operations research* in this country.

After the war operations research (OR) found its way into industry. Interdisciplinary teams, using objective investigation methods supported by advanced mathematics, probed operational problems in ways hitherto untried. Their procedures were abetted by the improving capabilities of computers. Without the capacity of computers for processing vast collections of data and solving complex equations, math-oriented solution methods would not have been adopted so readily.

The freshness of OR attracted both young scientific minds and established leaders in business and education. They used quantitative analysis to explore almost every province of management activity. Many felt the name operations research was too restrictive. The perhaps presumptuous but certainly inclusive title of *management science* emerged.

Every school of management theory is difficult to characterize in a few words, and management science is no exception. The still expanding boundaries of the subject make accurate description difficult.

Its evolutionary nature is aptly traced by William Morris:

> It is in no way prejudicial to suggest that management science is best characterized as on its way to becoming a science. Its contributors in general are scientifically trained, understand the requirements for an activity to be a science, have made great progress in the proper direction, and have encountered no provably insurmountable obstacles. The sole reason for the 'on-its-way' view is that management science's findings are as yet far from the generality of those of, say, physics. But it shares this emergence with many other sciences.[16]

The broadness of management science is further attested to by David Miller and Martin Starr:

> Management science is concerned with both short- and long-range planning. At present, it is likely to be far more effective (directly) in short-range circumstances. Nevertheless, it attempts to establish whatever relationships exist between an organization's objectives and its resources. In this way, it cuts across the traditional areas of management. Such crossing of boundaries characterizes management science, which is *problem-oriented.*[17]

The obvious strength of management science is its objective, quantitative treatment of management problems. This treatment is characterized by (1) a statement of the problem in a mathematical form, (2) reliance on measurable qualities such as costs and revenues, (3) use of computers, and (4) a dedication to rational decision making.

Let us not forget that a purely mathematical approach can have faults. Problems relating to people do not readily lend themselves to the use of numbers. Only a few aspects of human behavior can be represented in a mathematical model. Management scientists cannot be accused of avoiding behavioral issues, however, because they do consider them when quantification is possible. They know that successful implementation of actions suggested by mathematical models almost always relies on person to person dealings. While the models provide advice for closely defined situations, they cannot possibly specify everything a manager should consider while deciding.

Scientists have been developing models of physical systems for a long time. $E = mc^2$ is Einstein's famous, familiar, but seldom fully understood, expression of a governing physical phenomenon. $P = R - C$ (profit equals revenue minus cost) is a businessman's formula. Both are models used to explain the relationship between relevant factors that are influential in certain situations. Rather crude expressions of basic cost relationships have been around the business world for ages, but extensive use of sophisticated models by managers is quite recent. Acceptance of more elaborate modeling is retarded by lack of understanding, even some distrust, of how models can assist management decision making.

*A model is a representation of reality.* In management science, a model includes selected relevant factors of an actual system and is designed to explain certain aspects of the system's behavior. The model generally simplifies reality but closely approximates the more important elements under investigation.

Some models are intended to describe the actual condition of a system and others to describe what the model builder thinks the system should be. One type is a *descriptive* model and is usually developed to learn more about a present situation. The other type is a *normative* model and is constructed to show how things ought to be arranged to accomplish a particular objective. The difference in intentions between the two types may seem insignificant until you consider personal bias. People with slanted views can easily alter the development of a descriptive model to make it reflect their attitudes. They confuse issues by juggling statistics to paint whatever picture they choose.

Models can also be classified as to how closely they resemble reality. Physical look-alike models utilize a change in scale to reduce handling problems. Miniature airplanes and 3-D plant mockups are examples. Schematic models such as architectural sketches or production blueprints display two-dimensional relationships. Analog models are the most abstract and the most common in management science. Analogs do not resemble their prototypes at all; an electrical circuit could be the model for communications in a business firm, or a formula can represent a business situation such as the price-demand relationship for a product. Analog models are the most versatile but require extra caution to ensure they are meaningful in the real world they symbolize.

Figure 1-7 is a two-dimensional descriptive analog model frequently used in managerial decisions. The two lines at the bottom of the graph represent inversely

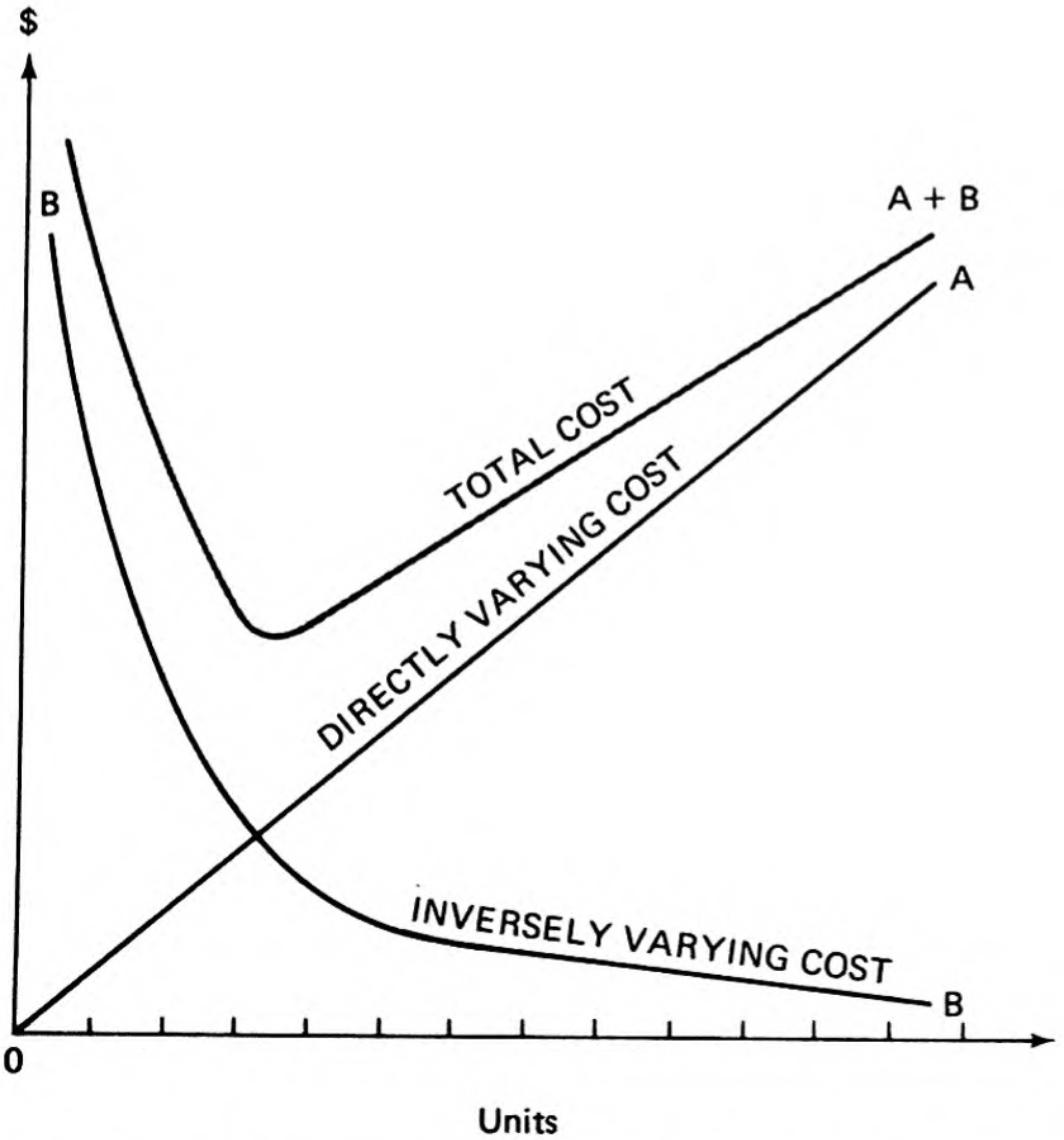


*Fig. 1-7. Minimum total cost point determined from the sum of the directly and inversely varying costs.*

varying cost (line B) and directly varying cost (line A). The top line is the sum of the lower two varying costs and is called the total cost curve. The lowest point on this curve indicates the number on the horizontal scale where total cost for the prototype process is least. As an example, the graph could represent a repair problem, with the units of time scaled on the horizontal axis. Then line A would designate the cost of an idle facility (renting replacement equipment, extra cost of buying parts not produced, etc.) and line B would show the cost of making repairs (decreasing repair time disproportionately increases the cost due to overtime payments, hiring extra help, etc.). The point on the time scale directly below the bottom point of the total cost curve marks the most economical repair time.

The same minimum cost situation can be described by a mathematical model:

$$\text{Total cost} = AX + \frac{B}{X}$$

where $X$ = the design variable (such as the units of production)
$A$ = cost per unit (a constant cost for all units such as the purchase price)
$B$ = unit cost (a constant cost for a function such as storing all the units)

After some algebraic manipulations (see Chapter 11), the value of $X$ that identifies the minimum cost is found to be $X = \sqrt{B/A}$. Again using the repair problem as an example, assume $X$ is units of hours, $A$ equals \$50 per hour outage cost, and $B$ is \$1,800 to do the repairs in the minimum time of one hour, making the repair cost \$900 if two hours are allowed, \$600 at three hours, etc. Then the most economical repair time is $X = \sqrt{1{,}800/50} = \sqrt{36} = 6$ hours and the minimum cost is $(\$50 \times 6) + (\$1{,}800/6) = \$300 + \$300 = \$600$.

Whether a graphic or a mathematical model is more appropriate depends on our purpose. If our goal is to determine X, the mathematical version is superior. But when our purpose is to explain a situation or to impress an audience with a potential trend, a visual model is advantageous. In either case, the models provide a formal framework from which to judge and think about problem areas.

## BEHIND THE FACES OF MANAGEMENT

From the foregoing survey of management theories it is evident there are many specialized areas. Perhaps the differences are more apparent than real. Some of the superficial differences are explained by the historical sources of the specialties.

Early investigators sought truths of management that would be counterparts to the universal truths of physical sciences which were being proclaimed at the turn of this century. Scientific management and management processes schools were two thrusts in the same drive to identify fundamental principles. Since these principles came from the rather narrow base of personal experiences, later researchers broadened their scope of inquiry. Their research contributions in human and social behavior parallel the concerns of society in general. The most recent advances in management theory are quantitative in nature; they mirror current developments in other fields to improve measuring techniques and to take advantage of the quick calculations of computers for more sophisticated mathematical manipulations.

Thus, with the vantage of hindsight, we can see that developments in managerial thought seem to parallel developments in other fields. This seemingly parallel growth with progress in other technologies offers an intriguing window to the future. We can expect continued refinements in computers and look forward to even more complete census-like data accumulations. Also, the social trend toward increasing emphasis on consumer services appears deep-rooted. Reaction to these trends may initiate a new management face, or at least a new wrinkle, that uses quantitative analyses of social trends to assist socially sensitive business planning and policy making.

## MANAGING THE MANAGEMENT MAZE

An aspiring manager might well wonder at all the entanglements of management theory. He may ask, "Do I have to absorb all those theories and fine points to be a superior manager?" The answer is a qualified no. While he certainly does not have to have *all* the current managerial tools, he surely will benefit from an awareness of those currently available. Certainly he owes himself basic competence in those skills relevant to his particular business pursuits.

Managerial skill is a two-phase endeavor. The first, breadth, comes from a survey of existing concepts. Acquisitions from this survey should include an up-to-date vocabulary, awareness of practices suggested by representative studies, and familiarity with proved, practical analytical tools. This accumulation gives the beginning manager sufficient skills to manage, yet these new skills may be potentially dangerous to him. He has still to learn where to do what and what to do where.

The second, depth, comes from experience. No survey or textbook can give it to you. As a natural process, managers tend to become specialized as a result of personal interest and job exposure. Experience then yields more depth of knowledge in their area of specialization.

Our brief survey, "Faces of Management," is a preliminary introduction. What follows in this book is a more detailed survey of management topics. Not all areas of management receive equal representation: some offer more immediate and practical applications are therefore emphasized. The authors strongly believe that initial studies which stress widely used visual tools are easy to appreciate and will encourage continued interest. To this end, they have selected how-to-do-it areas and have continually relied on illustrations, the graphic art of management.

## FUNCTIONAL AREAS OF MANAGEMENT

The prime issue in studying management is to decide what managers do. A safe start is to assume they manage. The dictionary says a person manages when he controls the action and succeeds in accomplishing tasks. This idea agrees with Fayol's divisions of management functions: (1) Planning, (2) Organizing, (3) Commanding, (4) Coordinating, and (5) Controlling. We can generalize these and other definitions by simply saying *managers decide what to do, organize whatever resources are required to do it, and then conduct a controlled series of actions.*

The trouble with simple definitions is that they apply generally to every case but provide very little guidance in any specific case. A helpful focus is to identify

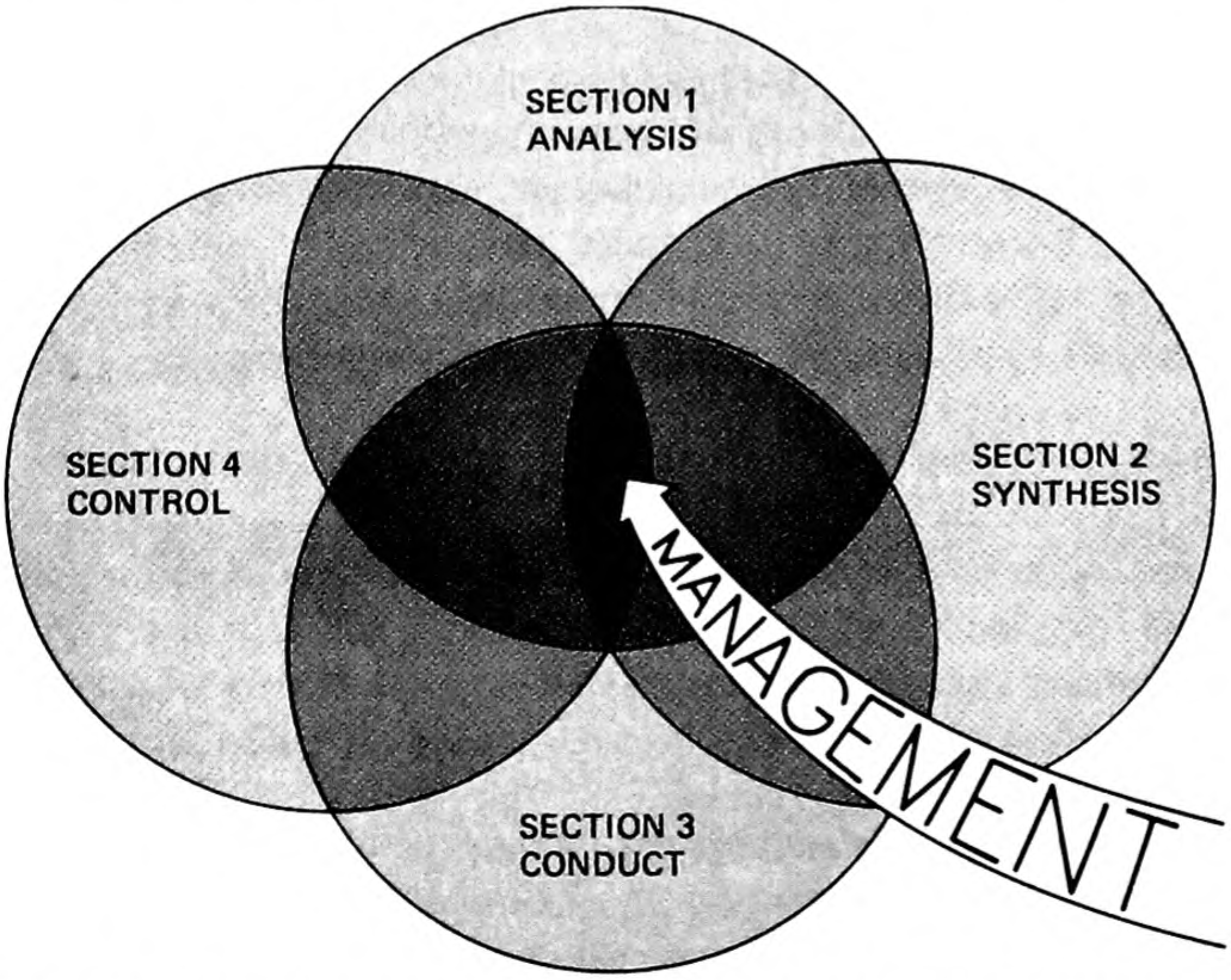


*Fig. 1-8. Management as the integration of four individually important functions.*

discrete actions common to managers in a number of disciplines. In Figure 1-8, management is depicted as the sum of the overlapping functions of *analysis, synthesis, conduct,* and *control.* These four functions are appropriately the four divisions of this text.

*Analysis* is a study of the parts of a system to reveal their effect upon operations. *Synthesis* is an attempt to relate those parts in such a way as to improve operations. *Conduct* is the organized effort made to direct overall operations effectively. *Control* is the guard against inferior conduct. But short definitions do not expose the full meaning.

As an explanation of management, these functions have a *synergistic* relationship. That is, the four parts as an integrated whole have more effect and more meaning than they do as four distinct entities. For example, the overlap between *control* and *analysis* represents the information gained from monitoring operations. This information is then analyzed to improve performance the next time the operation is conducted. Similar synergistic meanings can be derived from each overlapping segment. The four-layer overlap has special significance because the core area provides a pictorial definition of management.

Each functional area of management is an umbrella shadowing many specific action areas. The interlocking circles of Figure 1-8 are subdivided in Figure 1-9 to portray some of the more significant managerial actions. Note that verbs describe the type of action in each. We have also used these verbs as chapter titles to designate the type of activity most closely associated with each collection of management concepts and tools.

Division and subdivision of the management theme into functional and action areas is somewhat an academic exercise; that is, the partitions are artificial in that a manager cannot work in just one division at a time; he has to draw on information gained from other operations and to anticipate the effect of current considerations on related activities. Yet the partitions are logical. They provide a framework from which to study managerial qualities with minimum distraction from routine or repetitious applications.

Recognition of action areas also has practical advantages. The verbs act as reminders of what a manager should be doing. In the same way that college students easily lose sight of their career objectives in the rush of course scheduling and meeting daily assignments, managers often get preoccupied with routine administration of stopgap measures at the expense of synergistic execution. A quick reference to the action areas can help stimulate zeal in applying new or recalled management instruments. The know-how is available. All it needs is application.

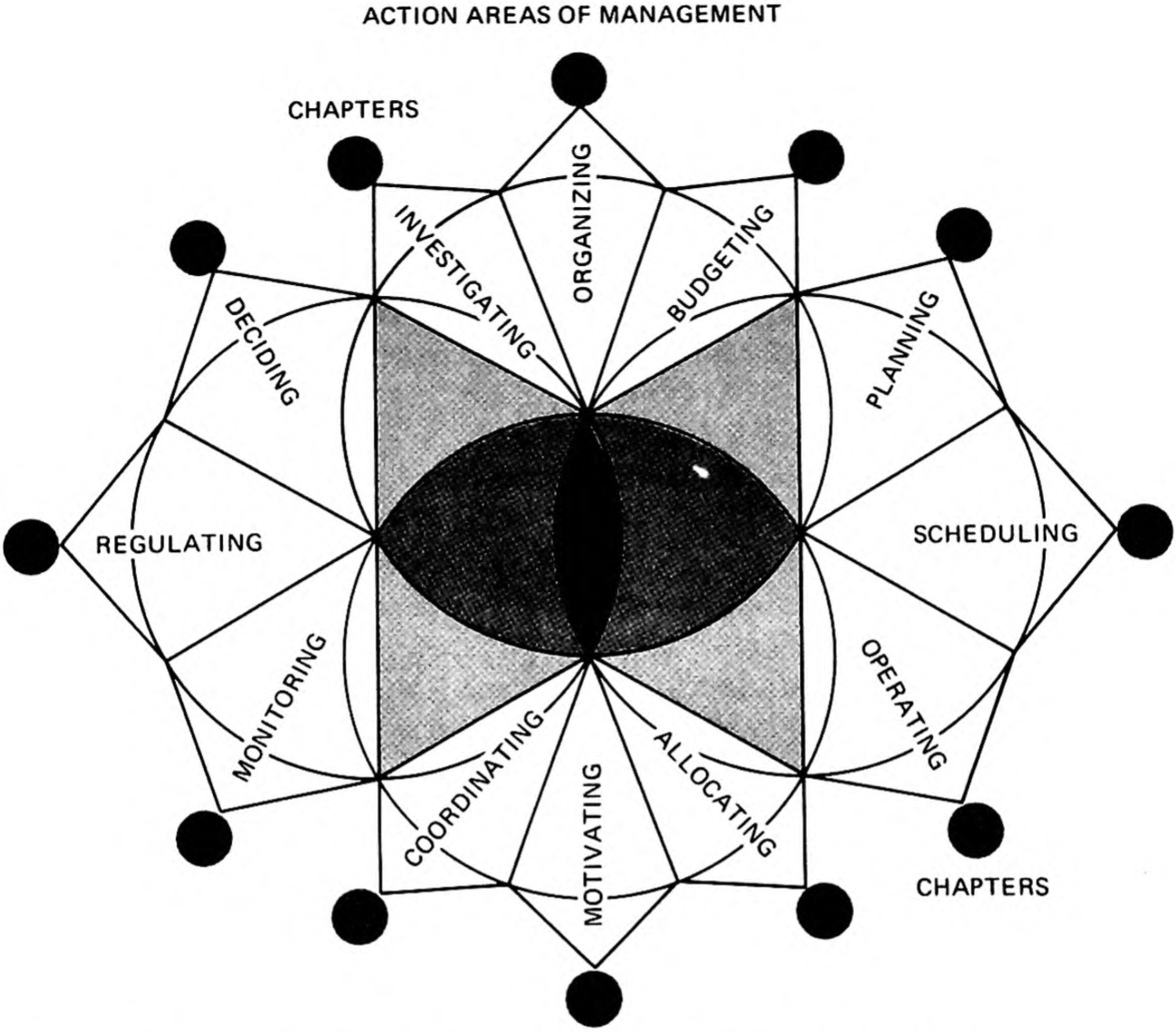

ACTION AREAS OF MANAGEMENT
CHAPTERS
ORGANIZING
INVESTIGATING
BUDGETING
DECIDING
PLANNING
REGULATING
SCHEDULING
MONITORING
OPERATING
COORDINATING
MOTIVATING
ALLOCATING
CHAPTERS

*Fig. 1-9. Chapters of the text dealing with the action areas of management.*

## REFERENCES

1. Stafford Beer, *Management Science—The Business Use of Operations Research,* Doubleday & Company, Inc., Garden City, N. Y., 1968.
2. Frederick W. Taylor, *Principles of Scientific Management,* Harper & Brothers, New York, 1919 (reprinted in *Scientific Management,* Harper & Brothers, New York, 1947).
3. Henri Fayol, *General and Industrial Management,* Sir Isaac Pitman & Sons, Ltd., London, 1949.
4. The divisions closely conform to those in Harold Koontz and Cyril O'Donnell's *Principles of Management,* 4th ed., McGraw-Hill Book Company, New York, 1968; and in W. Warren Haynes and Joseph L. Massie's *Management,* 2d ed. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1969.
5. Henri Fayol, *op. cit.*

6. Lyndall Urwick, *The Elements of Administration,* Harper & Brothers, New York, 1944.
7. James D. Mooney, *The Principles of Organization,* Harper & Brothers, New York, 1947.
8. From Urwick's "Are the Classics Really Out of Date?" *Management Journal,* July 1969.
9. Details are discussed in Fritz J. Roethlisberger and W. J. Dickson's *Management and the Worker,* Harvard University Press, Cambridge, Mass., 1939; and Elton Mayo's *The Human Problems of an Industrial Civilization,* Harvard University Press, Cambridge, Mass., 1946.
10. Adapted from Abraham H. Maslow's *Motivation and Personality,* Harper & Brothers, New York, 1954.
11. Chester I. Barnard, *The Function of the Executive,* Harvard University Press, Cambridge, Mass., 1938.
12. Interesting historical notes and a discussion of modern utility theory concepts are included in R. D. Luce and P. Suppes, "Preference, Utility, and Subjectivity" in *Handbook of Mathematical Psychology,* eds. R. D. Luce, R.R. Bush, and E. Galanter, vol. 3, John Wiley & Sons, Inc., New York, 1965.
13. John von Neuman and Oscar Morgenstern, *Theory of Games and Economic Behavior,* 2d ed., Princeton University Press, Princeton, N.J., 1947.
14. Abraham Wald, *Statistical Decision Functions,* John Wiley & Sons, Inc., New York, 1948.
15. Norbert Wiener, *Cybernetics,* John Wiley & Sons, Inc., New York, 1948.
16. William T. Morris, *Management Science in Action,* Richard D. Irwin, Inc., Homewood, Ill., 1963.
17. David W. Miller and Martin K. Starr, *Executive Decisions and Operations Research,* 2d ed., Prentice-Hall, Inc., Englewood Cliffs, N.J., 1969.

# SECTION 1
# ANALYSIS

It is best to do things
systematically, since we
are only humans, and disorder
is our worst enemy.

HESIOD
*Works and Days,* 8th century B.C.

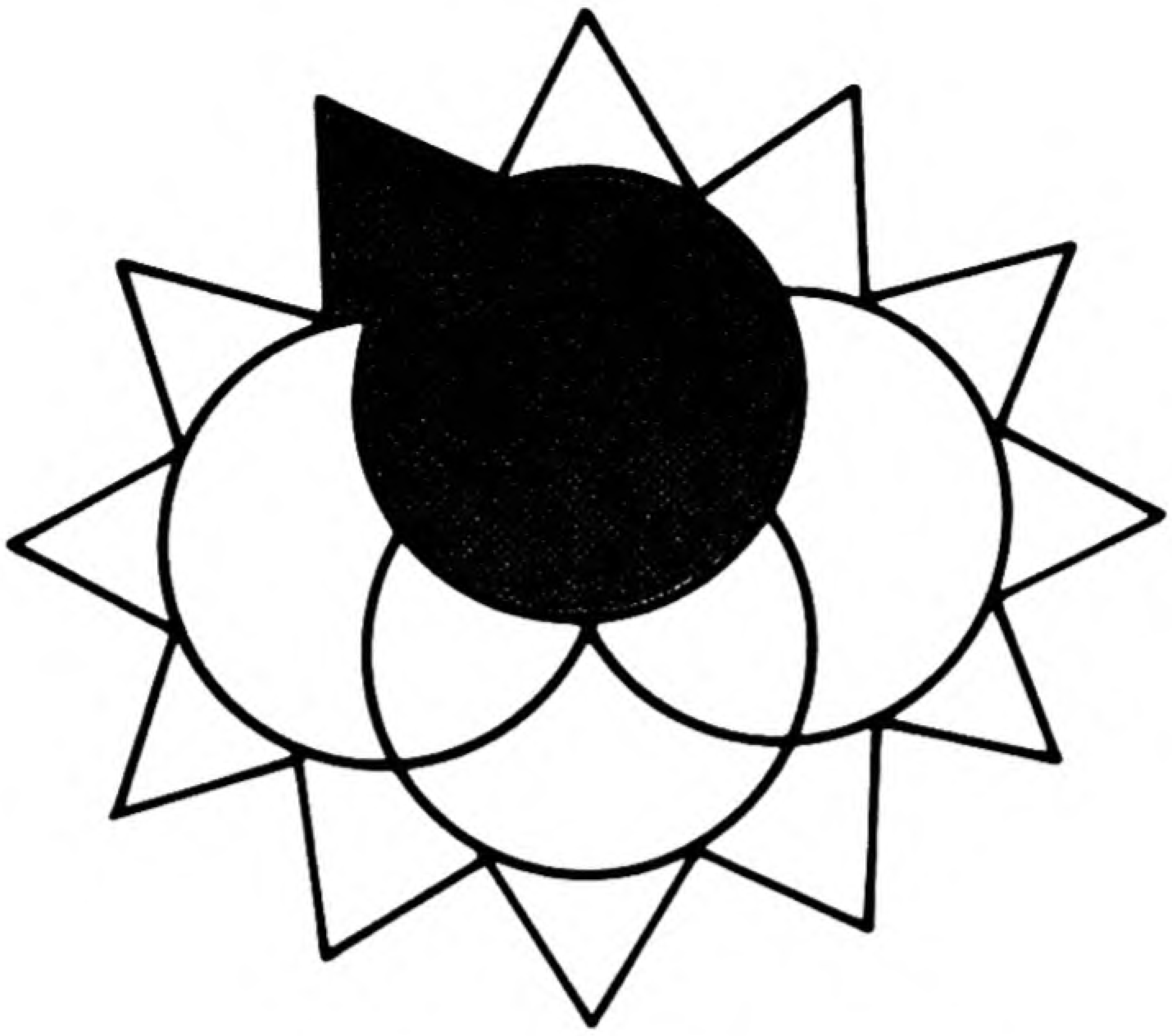
If you were asked to analyze your day's activities, you would probably start by grouping your actions into categories. When managers analyze their business activities, they begin the same way. Analysis is conducted by breaking up a whole into its component parts to better understand the relationship of the parts and the nature of the whole. The way the whole is broken up may determine the success of the analysis. Random facts collected into haphazard categories almost ensure a garbled picture, which leads to distorted interpretations. Effective analysis begins with well-conceived objectives. It continues with a well-organized search. And it culminates with an accurate evaluation.

Analyzing takes time. Anything that consumes time, in a business sense, consumes money. Consequently, managers decide whether something is worth analyzing before launching an investigation. After determining that a problem is indeed worth analyzing, most investigations follow essentially the same sequence of activities. The degree of thoroughness and creativity we bring to any effort establishes its quality. Any investigation benefits from the techniques contained in Chapter 2, "Investigating."

Since managers focus most of their analyses on problems confronting the organizations they serve, the kind of organization directly influences both the purpose and the process of their analyses. The scope of management responsibilities varies according to organizational patterns. The effects of different business patterns on communications, planning, and coordination are described in Chapter 3, "Organizing."

Most activities of an organization are eventually expressed as dollars. Similarly, most managerial analyses eventually are evaluated in monetary terms. The relationship of costs and revenues to operations is a guiding force behind business decisions. Budgeting decisions are made by comparing the economic effect of competing proposals. Financial statements, economic relationships, and investment comparison methods are discussed in Chapter 4, "Budgeting."

# Chapter 2



# Investigating

**KEY SUBJECTS**

Before a manager can make a decision, he has to have facts. To obtain facts, he must search, examine, and inquire. We call this process "investigating." *One of the tougher tasks in managing is to decide how much investigative effort you should devote to solving each of the many problems you encounter daily.* A manager has to ask himself continually, "Now, which of these problems is the most urgent and most serious? The day is only so long, and I want to use my time wisely." He will give quick treatment to trivial matters. He may use standard operating routines for problems which involve more cost, time, or resources. Some larger problems may require a serious search for a solution.

*In order for his efforts to bring the best results on important problems, the manager must have a definite work plan and an organized system for investigating.* Investigations tend to follow either experimental or heuristic patterns. The former rely heavily on predictive models and the latter lean towards experience and judgment. Neither approach guarantees an answer, and both are subject to realistic practices that blend idealism with expediency to secure acceptable but not necessarily optimum solutions.

Every problem has a large number of possible answers. A searcher will never recognize some, and genuine or fictitious restrictions imposed on him will eliminate others. Among the remaining answers the alternatives vary in quality. An effective searcher samples as many alternatives as possible while avoiding mental barriers that restrict his preferences to familiar situations.

*Unique and novel solutions are more likely when investigators intentionally strive for creativity.* Many ideation techniques do produce ideas. Trigger words, checklists, characteristic appraisals, factor sketches, and matrices are most useful for individuals. Brainstorming or synectic sessions seem good for groups. Creativity apparently is not an inherited talent, but one that can be cultivated by a willingness to endure the frustrations of sterile periods and a willingness to apply the mental discipline needed to discover the unusual.

*Diagraming the factors involved in a problem assists in organizing and interpreting data.* Cause and effect diagrams portray the relationship of factors to make their influence more observable. Labeled arrows representing problem conditions are linked together to show natural groupings and the relative effect of factors within groups. Different C&E formats can emphasize special aspects such as the sequence of events or the richness of a study.

## SERVICE CALLS

Many items vie for a manager's time during the course of a day. Most items are rather commonplace—easily handled with little trouble. A few deserve careful examination. Consider a token example of an office manager who found three messages lying on his desk one morning.

The first message was a scribbled note from the janitor. It reported that the supply of yellow napkins in the canteen was almost exhausted and the replacements would have to be either white or brown. Which color was preferable?

The second note was from the switchboard operator. It said that Mary, one of the staff members in the office, was sick with the flu and would be out for the rest of the week.

The third message was a directive from a vice president to attend a meeting a week later and to be prepared to take a stand on the advisability of changing from a 40-hour, five-day week to a four-day week of 10 hours per day.

All the messages require some kind of action by the manager. The janitor's question is the kind that would be answered by a simple judgment, a reflex response. Rescheduling work assignments to compensate for the absent staff member requires more effort because other workers are involved, but the task is a familiar one and therefore not too pressing. The four-day workweek is a pressing question. It has long-range effects, touches people and operations both inside and outside the firm, and poses several economic consequences. A proposal of this magnitude deserves more than an opinion drawn from personal experiences; it warrants in-depth study.

## DEPTH GAUGES

Each manager has to decide how much effort he can allot to the many calls for his services. It is not an easy decision. He has to compare the urgency and gravity of the need with his overall commitment. What is a major undertaking at one level of management is just a single part of the picture a higher level views as its commitment. Each level of management has the responsibility to inform the level below of its rights and responsibilities. Many haggard managers owe their anxiety to an inability to find out what is really expected of them or how much latitude they have in achieving expectations.

Even whan a manager knows the bounds of his responsibilities, he still has to ration his efforts. It would be absurd to devote the same amount of consideration to a color selection for napkins as to a choice between a four- or five-day workweek. The relative amount of effort deserved in such cases is quite easy to gauge, but the actual amount for each is less apparent. The unceasing parade of problems keeps a manager from finding the ideal answer for each one. There are limits to a manager's time and energy, and the reservoir of problems seems infinite.

A depth gauge is needed to help measure how much involvement different problems merit. The gauge must be personalized because capacities and capabilities vary among managers. It will change with time as duties shift. But there are some general guides common to all situations. Responses to questions or problems can be categorized to help judge how deep an investigation is warranted.

### Reflex Response

A trivial matter merits a trifling response. The challenge is to identify the point where matters jump from trivial to significant. A good indication is obtained by considering the *sensitivity* of the situation with respect to three criteria: time, cost, and extent of resource involvement. The three criteria are the axes for the chart in Figure 2-1.

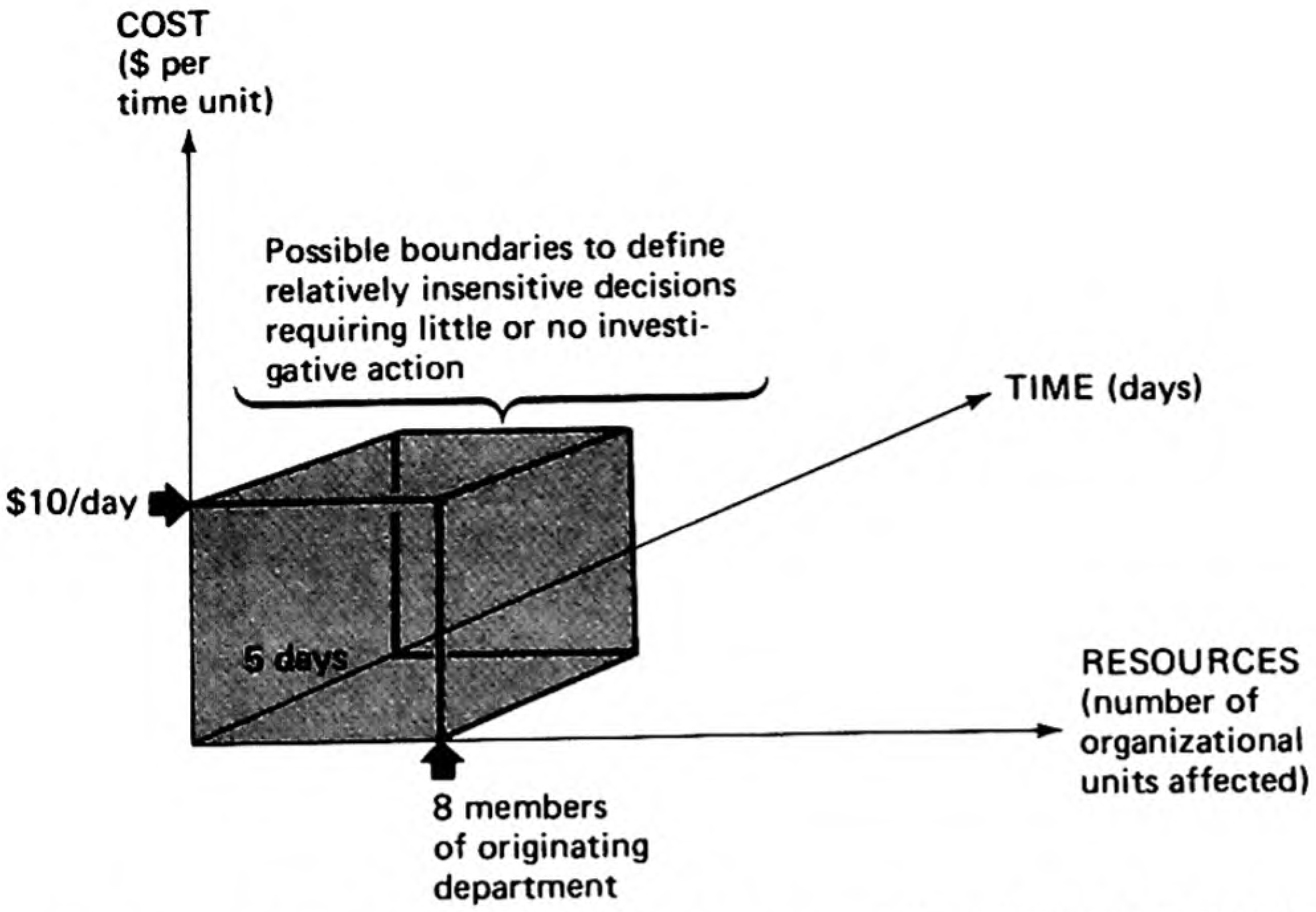

COST
($ per
time unit)
Possible boundaries to define
relatively insensitive decisions
requiring little or no investigative action
TIME (days)
$10/day
5 days
RESOURCES
(number of
organizational
units affected)
8 members
of originating
department

*Fig. 2-1. A graph of three criteria for determining the sensitivity of a response to a problem.*

Assuming that a manager knows what resources he can call on, his limits of responsibility, and the objectives of his unit, he can visualize the boundaries for reflex responses without much difficulty. They do not have to be exact. They are guides at first and then become reminders as procedures become more automatic. The possible boundaries in Figure 2-1 suggest that, if you have an action involving a small work group, limited expense, and a short-range effect, it might be conducted with minimum preparation. Such rubber-stamp decisions are usually just an approval of someone else's actions. They keep the manager informed and draw on his experience to judge correctness. He can make the judgment quickly and comfortably.

### Routine Response

Uncomfortable feelings are often aroused by situations where an automatic action is *almost* legitimate. Perhaps the cost and time criteria indicate a reflex response, but the number of people affected suggests a closer examination. Then it is necessary to do a bit of internal searching for assurance.

Most routine actions are guided by *standard operating procedures* (SOP). These guidelines may be either written formal procedures or hereditary informal practices. They are based on what has worked in the past. There is always some danger that the methods will not work for present situations, but they still provide a standard by which to judge any necessary deviations.

When no SOP fits the occasion a problem solver turns elsewhere for clues. By definition, routine-response situations do not warrant intensive investigations.

Therefore, advice must be sought from inexpensive, convenient sources. Personal experience is often the best source of this kind of advice; this is why experienced managers get higher pay. When such a manager can adapt his experiences to solve a type of problem he has never before encountered, he is worth even more. We will look into creative abilities later in this chapter. Additional information can come from a tremendous number of sources. Almost everyone, no matter how vaguely he is associated with a situation, has an opinion to offer. People, books, magazines, trade journals, reports, financial accounts, company records and many other written documents can be consulted if there is enough time available. The mark of a successful manager is his ability to ferret out quickly appropriate data from vast arrays of potential sources. He can augment his memory with tickle files (annotations collected by subject headings, often on alphabetized cards), subscription digests (brief summaries of selected works provided by library or management services), and notes taken during seminars and conferences.

The opposite of overabundance of information is a scarcity of it. Yet the two extremes can produce similar feelings of uneasiness; the confusion sometimes created by securing many different viewpoints is akin to the panic that arises when none of the viewpoints are quite appropriate. Both situations can tempt a manager to guess.

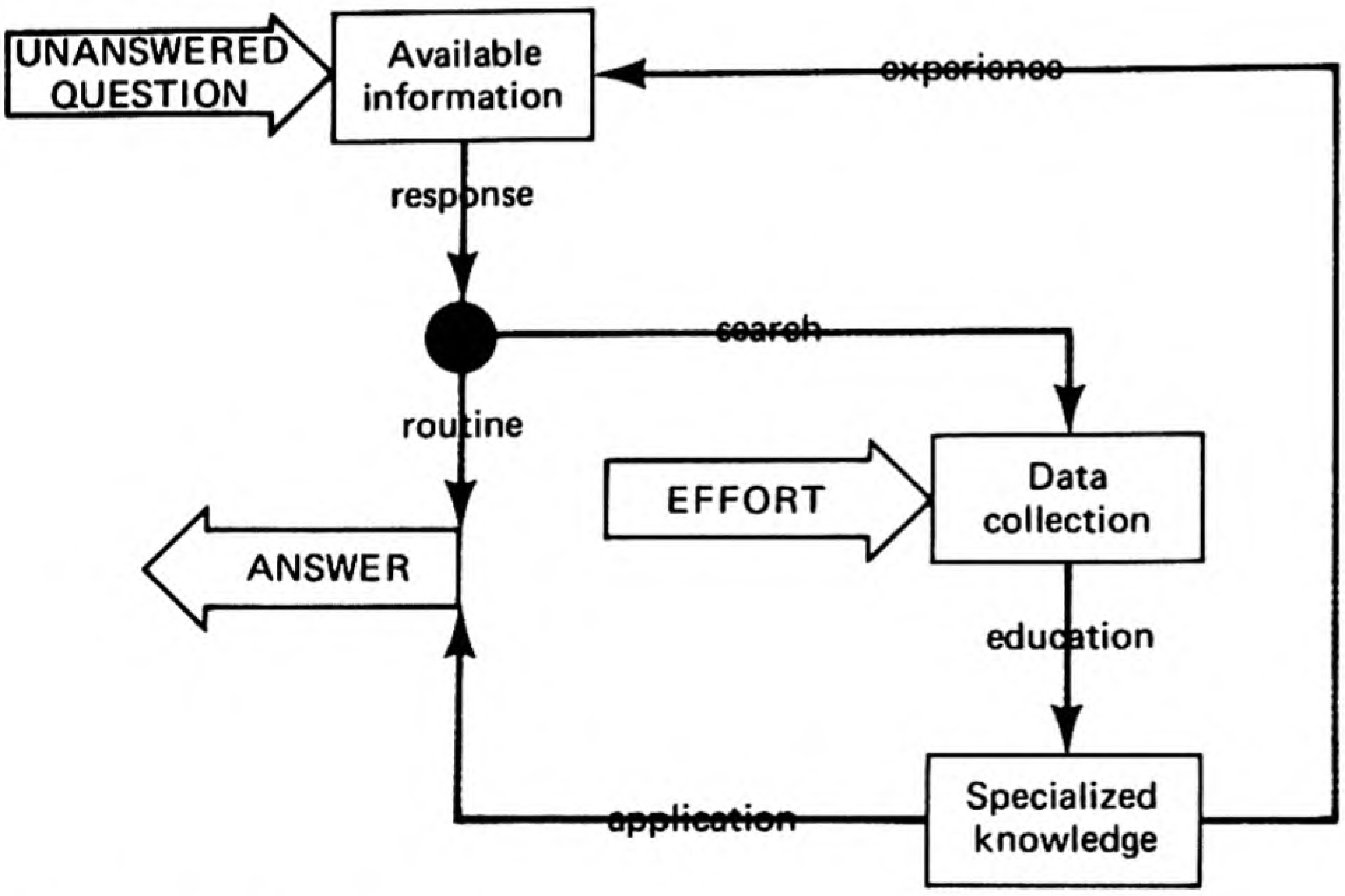


*Fig. 2-2. A flowchart for problem investigation: an* unanswered question *is judged on the basis of* available information. *The* response *can be an answer drawn from the information available or a decision to search for more information. The search requires* effort *to* collect data. *These data may lead to* specialized knowledge *that will produce a solution as good or better than the response made without additional information. The* educational *value of the collected data feeds back through the* experience *loop to increase the fund of information available for answering the next problem.*

A condition of uneasiness should not be alarming. It is just one of the challenges of management; a completely secure environment hardly needs a manager. In practice, evaluating the adequacy of information is a self-regulating process. Consider an occasion where you faced a routine response: say, whether to prepare a report or to do something more exciting. With regard to adequacy of information, you could be in one of two positions. (1) Adequate information would put you in the secure position of knowing what to do. (2) Inadequate information should give you a feeling of uneasiness; you cannot confidently determine consequences, benefits, rewards, and regrets. Just recognizing the state of uneasiness implies that you know something about the problem. Absolute ignorance would have made you indifferent. Therefore, you are in the gray area where the art of management is useful. You will have to judge the penalty which would result from a poor solution against the effort required to gain a better chance for a good solution. A judgment to seek more data comes from having enough information to know additional details are worth seeking. The process is depicted in Figure 2-2.

### Research Response

The "search" option in Figure 2-2 is a multilevel alternative ranging from a spontaneous quest for information to a deep, methodical investigation. A research response is a commitment to allot enough resources to have a reasonable chance of discovering the information sought. Whereas a routine response implies a survey of worked-out answers to find the one that would fit the question, a research response pledges a concerted effort to evolve a solution which has not been reached before.

The popular concept of research seems to be a many pronged attack on a mysterious problem by laboratory experts endowed with boundless funds. Though overly dramatic, this view does grasp the complications and cost of a serious search for data. A thorough evaluation preceding the purchase of new machinery by a small company is a puny research undertaking when compared to big-budget teams unleashed by major corporations to make major discoveries, but both cases represent significant proportional investments. Even an individual effort by a manager to develop a customized solution takes its toll of time, temper, and neglected duties.

## SYSTEMATIC SEARCHES

Whether research is of a scientific nature or of the more literal version, *re-search* sponsored by front-line managers, a systematic program has a better chance for

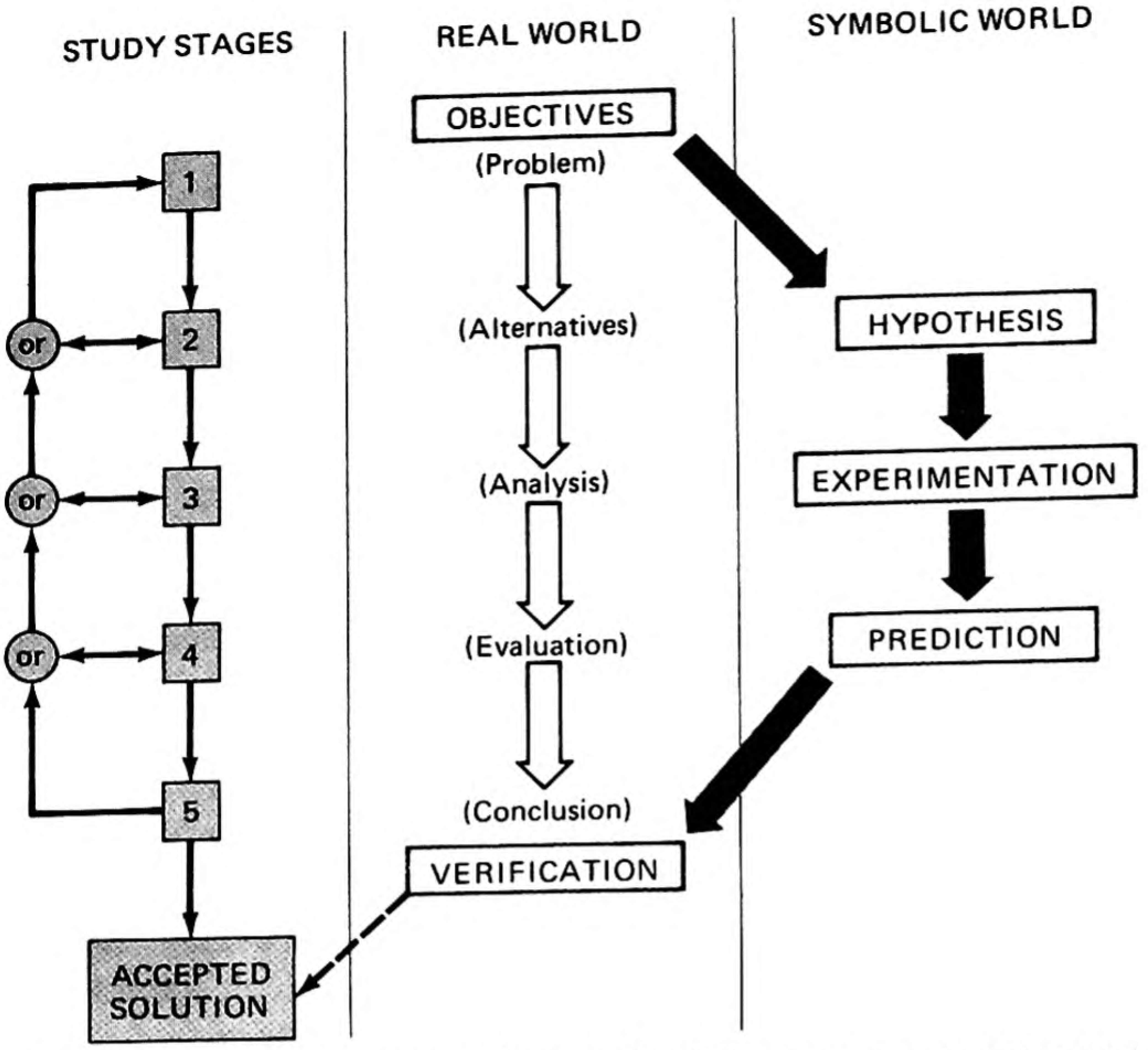

STUDY STAGES
REAL WORLD
SYMBOLIC WORLD
OBJECTIVES
(Problem)
(Alternatives)
(Analysis)
(Evaluation)
(Conclusion)
VERIFICATION
HYPOTHESIS
EXPERIMENTATION
PREDICTION
1
2
3
4
5
or
or
or
ACCEPTED SOLUTION

*Fig. 2-3. Stages of a research investigation using an* experimental *(gray arrows) or a* heuristic *(white arrows) approach.*

success. Typical procedural stages of an investigation are shown in Figure 2-3. Although the study steps appear quite straightforward, many pitfalls occur in actual practice. We will explore the process by comparing the experimental and heuristic approaches, and then we will examine how they are conducted.

### Experimental Approach

The classical method of scientific investigation follows a step-by-step procedure for studying a phenomenon. A phenomenon in the business world is an unexplained but interesting event or series of events. It may not be a specific problem. Instead it is more likely to be a type of behavior which, if explained, would help solve several problems. Studies of consumer-buying habits, financial trends, new product introductions, and production methods are examples of this kind of investigation.

An investigation starts with a definition of objectives as shown in Figure 2-3. Considerable study often precedes the definition because the objectives establish both the purpose of the research and the criteria for evaluation. A common complaint by research and development (R&D) groups is that sponsoring departments want to know the solution before defining the problem so that they can choose their objectives. But this seemingly backward routine has its practical aspects. In order to decide whether a question is worth investigating and to fund it adequately, someone has to estimate the extent of the study, resources required, time schedules, and the probability of achieving desired results.

Sophisticated research relies extensively on models. A hypothesis, often in the form of a mathematical expression such as an equation relating profit, cost, and revenue, is offered as a tentative explanation of the matter being explored. This expression uses numbers and symbols to represent conditions in the real world. The figures may be altered, eliminated, or supplemented during the experimentation stage. The purpose is to find a combination that is a reasonably accurate model of actual behavior. Once the best fitting model is found, it is tested to see how well it continues to conform to the real-world situation. For example, an initial model to predict how long it takes a messenger to deliver a package from one building to another might be time in minutes = distance in feet/352. After timing the messenger on several deliveries and comparing his times with those predicted by the model, it might be found that the equation was accurate for flat uncrowded paths, but it was inaccurate for more demanding routes. Then it would be necessary to add more terms to the model to account for different obstacles that might be encountered. Again the model would be tested against actual delivery times. If the revised model continued to predict correctly, it would be accepted and the objective of the study would be satisfied.

As a short example of the experimental approach, suppose a manager wanted to know why the sales of one of the products of his division, doorbell chimes, varied so much. He recognized the phenomenon could not be explained by a routine response and he figured the savings in inventory costs from a valid sales predictor would easily pay the research costs. An assigned experimenter developed the hypothesis that sales were related to the number of retailers, construction activity, net personal income, and other factors in the sales area. He experimented with different formulas to determine how the factors were related and their relative importance. By inserting known values of the factors and actual sales from previous years, he tested the predictive worth of his mathematical model. After he was satisfied that the model was a valid representation of the real world, he subjected it to the ultimate verification by using it to predict next year's sales of doorbell chimes.

### Heuristic Approach

The word "heuristic" comes from a Greek root meaning *to discover*. As applied to problem solving, it means the use of logic and common sense. It does not mean a haphazard or lucky solution. A heuristic approach uses individual judgment to structure a study in the tradition of independent investigations. It incorporates experience and familiarity with a problem area to reduce the specific problem to more manageable proportions.

The informality of a heuristic approach is particularly appropriate for ill-structured or ill-defined problems and for investigations conducted by individuals with limited resources. This flexibility backfires when someone seeks to repeat a solution method or to duplicate part of it for retesting. Another disadvantage is the lack of assurance that the solution which emerges is the best one available. Both of these embarrassments are avoided by the rigor and rigidity of the experimental approach.

A heuristic search does not require a precisely defined problem in its first stage. The nature of the problem becomes clear as different possible solutions or solution methods are explored. The manager collects more information about alternatives during the analysis stage when he considers tentative effects of potential solutions. He selects a preferred alternative for close scrutiny, possibly based on intuition, but more likely on some proof of applicability. He bases his evaluation on factors discovered during the analysis. If the preferred alternative is still suitable after the evaluation, he chooses it for use.

Consider again the manager who is seeking to explain his erratic doorbell chime sales; suppose he decided to use a heuristic approach. His inadequate knowledge or lack of resources to support an experimental study could have caused him to make this choice. His election of an informal method avoids the need for a preliminary statement of objectives. Alone or with associates he dives into the problem to see what he needs. He could conclude that he really wants a forecast to use for planning rather than an explanation of why sales vary. From his experience he knows there are many forecasting methods available. He ponders the merits of those with which he is familiar. While pondering, he realizes that the sales of doorbell chimes should correlate closely with housing starts and, just as importantly, he remembers that home construction forecasts of high reliability are provided free by a government agency. His hunch about the correlation is confirmed when he checks past statistics on sales against the number of new homes constructed each year. This process appears simple and workable, but if asked how he got his answer, the manager would be at a loss to explain it.

### Sequence of Search

The indefinite nature of research is implied by the route-retracing arrows connecting the study stages in the left column of Figure 2-3. The research route from problem to solution is comparable to picking a path from one sector of a woods to another. At the starting point there may be several trails to choose from.

One that looks promising is chosen. It could lead straight through to the destination, or it could be blocked by an insurmountable obstacle that causes backtracking. If a restart is required, selection of a new trail is improved by the experience gained from the previous unsuccessful exploration; at least one trail is known to be worthless. Meanderings in the new trail might be avoided by shortcuts learned from observations made along the old trail. The latest path could be the answer, or it could lead nowhere.

So go the paths of research; some pierce straight through, some are indefinite and meander but still get there, some are circles, and some get you hopelessly lost. The following conditions and suggestions typify the complexities of research:

- A problem may be too big to be solved all at once. Perhaps it can be divided into more manageable parts.
- There may not be enough information available to draw a conclusion. Those reliable insights that have been secured can be applied either to a related problem or to a partial solution of the principal problem.
- A case of too much information can be relieved by narrowing the objectives of the research or by piecemeal analysis.
- A promising model from the symbolic world may fail testing in the real world. Repetition of the stages of the model may produce the "richness" necessary to represent reality.

Listings of difficulties in conducting research could extend almost endlessly. A good guideline in coping with the snags in research is the practice of *satisficing.* When you strive for a defined level of performance, but are forced to settle for a lesser level because the striving is getting too expensive, you are satisficing. The practice of satisficing is defended by the logic that it is better to accept a workable answer that may not be the best than to insist on an optimum solution that is not technically feasible. A satisficing investigation is one that produces an adequate answer without an exhaustive search, a blend of idealism and expediency.

## MENTAL SET FOR PROBLEM SOLVING

It goes without saying that a problem solver must first convince himself that a problem is worth solving before he can hope for a solution. The act of not acting on a problem is a choice—not a solution. A "put-off" habit is just a very expensive way to buy time; problems seldom get easier with age.

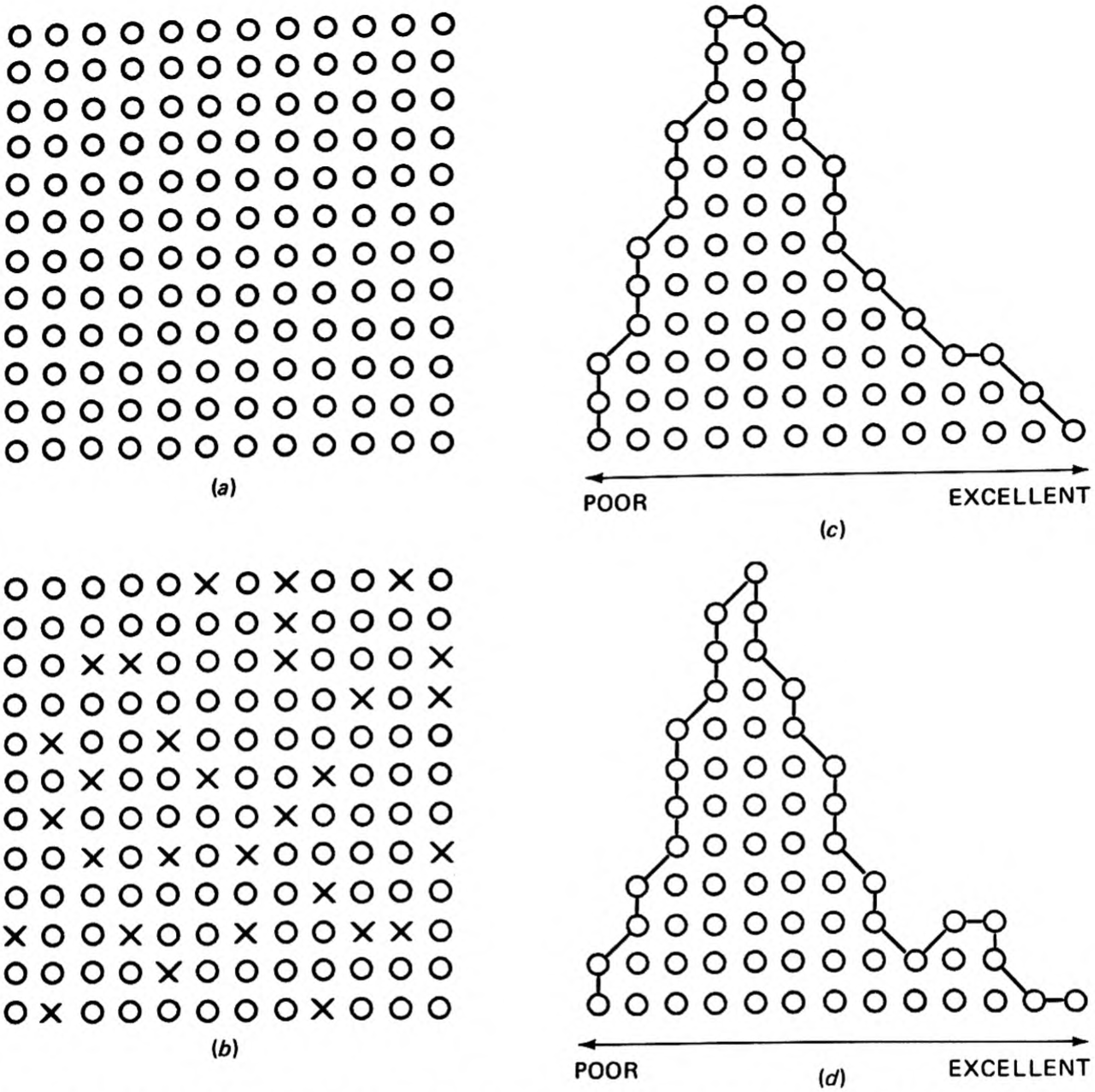


*Fig. 2-4. (a) Mental set for problem solving: universe of possible solutions for a certain type of problem; (b) number of possible solutions reduced by genuine restrictions peculiar to the specific problem; (c) feasible solutions grouped according to quality; (d) solution space reduced by the number of alternatives unrecognized or eliminated by fictitious requirements.*

A positive mental set is a state of preparedness. In problem solving it is an attitude to accomplish something and a desire to achieve it in the most effective manner.

Every problem has a wealth of potential solutions. Even a simple proposition that deserves a yes or no answer can be obscured by a "maybe." And "maybe" has many shades of meaning as any salesman will testify. A good problem solver will readily acknowledge the spectrum of answers available. To illustrate, let the array of circles in Figure 2-4*a* represent potential solutions to a single problem.

Only under very unusual circumstances would a problem solver have the resources or qualifications to investigate all possible solutions in seeking the best one. The situation is partially relieved by genuine restrictions peculiar to the specific problem conditions. These restrictions are imposed by operating circumstances such as an upper limit on money to be spent, preference for a certain color, maximum allowable weight, or familiar design. Valid restrictions narrow the choice to possible solutions which meet the specified characteristics. Crossed-off circles in Figure 2-4*b* represent alternatives eliminated from the original group of possible solutions by genuine restrictions.

The remaining possible solutions will fall somewhere in the range from very bad to very good. It is quite likely that most of the possible answers are neither extremely bad nor good. If grouped along a scale of quality, they would tend to form a pattern like that displayed in Figure 2-4*c*. This pattern would not be evident in practice because a problem solver rarely has the opportunity to identify all possible solutions and has even less chance to rate them.

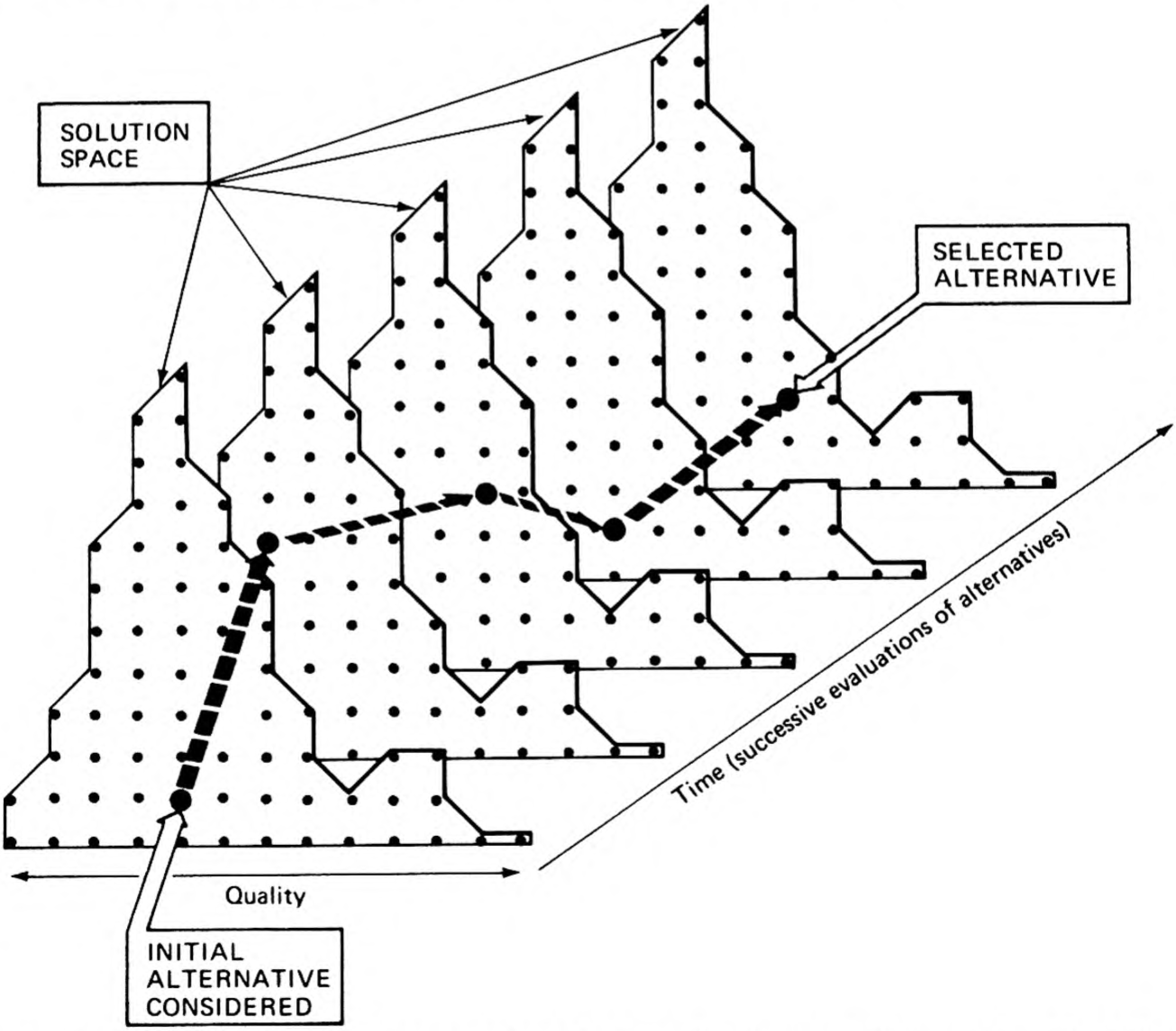

SOLUTION SPACE
SELECTED ALTERNATIVE
Time (successive evaluations of alternatives)
Quality
INITIAL ALTERNATIVE CONSIDERED

*Fig. 2-5. The search path for a preferred alternative in a solution space restricted by genuine, fictitious, and knowledge constraints.*

The actual solution space available would take some irregular shape such as that in Figure 2-4*d*. Many solutions are eliminated by the problem solver's lack of knowledge. A person must be aware that an alternative exists before it can be considered, and then it must conform to personal biases to remain in contention. Stereotyped responses to questions result from a solution space constricted by too few facts and too many prejudices.

While a solution space is a unique product of each person and problem, the final selection tends to follow a prevailing path. The route depicted in Figure 2-5 suggests three characteristics worthy of special note.

1. The starting point is usually a solution that has been used before for a similar problem. This is a natural choice but it has the potential of creating a halo effect that may blind the searcher from conceiving any other answer.
2. When other alternatives are investigated, they are frequently just minor modifications of the initial solution. It takes a concerted mental effort to spring away from the familiar in search of the novel. Thus the search pattern is restricted to a relatively small portion of the solution space.
3. Many searches cease before enough sample solutions have been surveyed. Both the halo effect and mediocre improvements recalled from customary alternatives are responsible for this limited sampling. Another reason is a conservative attitude. A major investment of effort is required to shop around the solution space, and there is a risk that the investment will not be repaid by discovery of a significantly better solution.

The foregoing practices are prevalent enough to be called habits. They are comfortable habits, grooved in the mind by time. And they are safe habits because they avoid exposing the searcher to exploratory risks; only the searcher really knows the diligence of his searches. But they also stifle productivity. A premeditated attempt to get fresh views could easily alter existing habits. That alteration is creativity.

## CREATIVITY

Any manager welcomes those rare instances when he is inspired by an original answer to a problem. He is delighted by the feelings of satisfaction and confidence that accompany a unique solution, but he cannot explain exactly what aroused his creativity. No one can.

In problem solving, creativity embodies both originality and relevance. Although it is quite easy to spout unique ideas, it is decidedly more difficult to create original responses that are relevant to the solution of a problem. As illustrated in Figure 2-5, a creative answer is the discovery of an alternative within the solution space that is far removed from a common response. The extent to which a choice is unusual and successful in solving the problem is a measure of the creativity displayed.

Many studies have been made in recent years to find out what causes and what can promote creative behavior. The mental mechanics of creativity have escaped detection, but several practical observations have been accepted. It appears that creativity is not an inherited talent; we all have it to some degree and it can be cultivated. There is apparently little or no correlation between high intelligence and greater creativity. Evidence indicates that creative behavior can be encouraged by the right environment and the application of certain techniques.

While no set sequence of events guarantees an inspired idea, a general pattern seems to accompany the creative process.

**IRRITATION.** The trigger to creative activity is discontent with a present situation. It takes a large measure of disturbance to overcome ingrained reluctance to seek a novel solution. The traits that seem to be associated with a creative person are the same ones often deplored by employers.* Our social structures tend to reward conformity. Thus the irritation must be severe enough to provoke unconventional behavior with its risk of ridicule for not conforming.

**INVESTIGATION.** A review of existing solutions frequently stimulates ideas for innovations or modifications. A search of printed information and conversations with informed associates can act as springboards for a leap in a new direction. But investigations can sidetrack creativity when they make the problem look too big to cope with or too narrow to allow innovations.

**INCUBATION.** The first phase of incubation is the intentional stirring together of many related facts, fantasies, incidents, associations, and similarities. It takes tight mental discipline to explore forcefully various combinations and still let thoughts run freely among possible permutations. The second phase involves the subconscious mind and is less well understood. Here the mind percolates around the problem trying different "forgotten" combinations; it reacts to the struggle and frustrations encountered in the conscious assault on the problem.

*J. H. McPherson, in "The Relationship of the Individual to the Creative Process in the Management Environment" (ASME Paper, May 1964), describes some characteristics of a highly creative person as "insensitive to feelings of others, enjoys nonconformity, says what he thinks, seeks privacy, accepts failure easily, and places little value on job security or status symbols."

**INSPIRATION.** Cartoon strips proclaim a bright idea by a glowing lightbulb hanging above the lucky originator. Stories circulate about inventors who wake up at night to have all the details of a new design suddenly unfold before their mind's eye. Complete solutions rarely reveal themselves in one stroke, but spontaneous eruptions of originality can happen. They usually occur during a rest period or a slack in activities when the subconscious mind seems most effective at probing for ideas. Some techniques designed to hasten flashes of illumination are discussed in later sections.

**INSPECTION.** Sometimes an exciting new thought loses its glow when evaluated by standards required for implementation. Failures should not be discouraging because really novel solutions are bound to be infrequent or they would not be original. The purpose of an inspection is to verify whether the original response is relevant to the problem. If it is workable, the problem is over. If not, back to the mental gymnastics.

## SOLO MIND EXPANDERS

The first few answers to a problem are relatively easy to accumulate. Successive answers get tougher to make. Eventually a frustrating stage may be reached where nothing is left to draw on. The well of ideas is dry and the problem is still unsolved. A rest period can usually alleviate the situation if there is enough time for it. A better remedy is the use of idea-stimulating techniques. Several are available. When one does not produce, another can be tried. All of them can be polished by practice and patience.

### Trigger Words

The purpose of trigger words is to stimulate imagination by progressing through a chain of related words or phrases. The subject of the chain is established by choosing an important characteristic of the problem. For instance, *size* might be a key factor in a problem. A chain is developed by collecting all the adjectives you can think of that apply to *size*: bigger, smaller, lighter, heavier, rounder, flatter, thinner, fatter, taller, shorter, least, most, partial, few, many, decreasing, increasing, puny, huge, slender, gross, etc. In other cases the chain might contain verbs or nouns. A thesaurus of synonyms is a treasury of triggers.

### Characteristic Assassination

Characteristics of a problem can be analyzed by assuming all of them are faulty. The situation is similar to interrogating a witness to disprove his testimony.

After listing the characteristics, each can be questioned by asking: What is done; why that way? Who does it; why does he do it? Where is it done; why there? When is it done; why then? How is it done; why that way? Answers to these questions are in turn subject to suspicion. Sometimes the doubts will lead to original interpretations.

Another approach which employs questions to seek useful associations is the use of checklists. Suggested lists can be followed or an innovator can develop his own to fit more closely the type of problem he usually faces. Alex F. Osborn in his *Applied Imagination* (Charles Scribner's Sons, New York, 1953) suggests key questions such as "adapt? modify? magnify? substitute? rearrange? reverse? combine?" etc. A customized list has the advantage of being based on known similarities and contrasts that encourage recall of half-forgotten experiences.

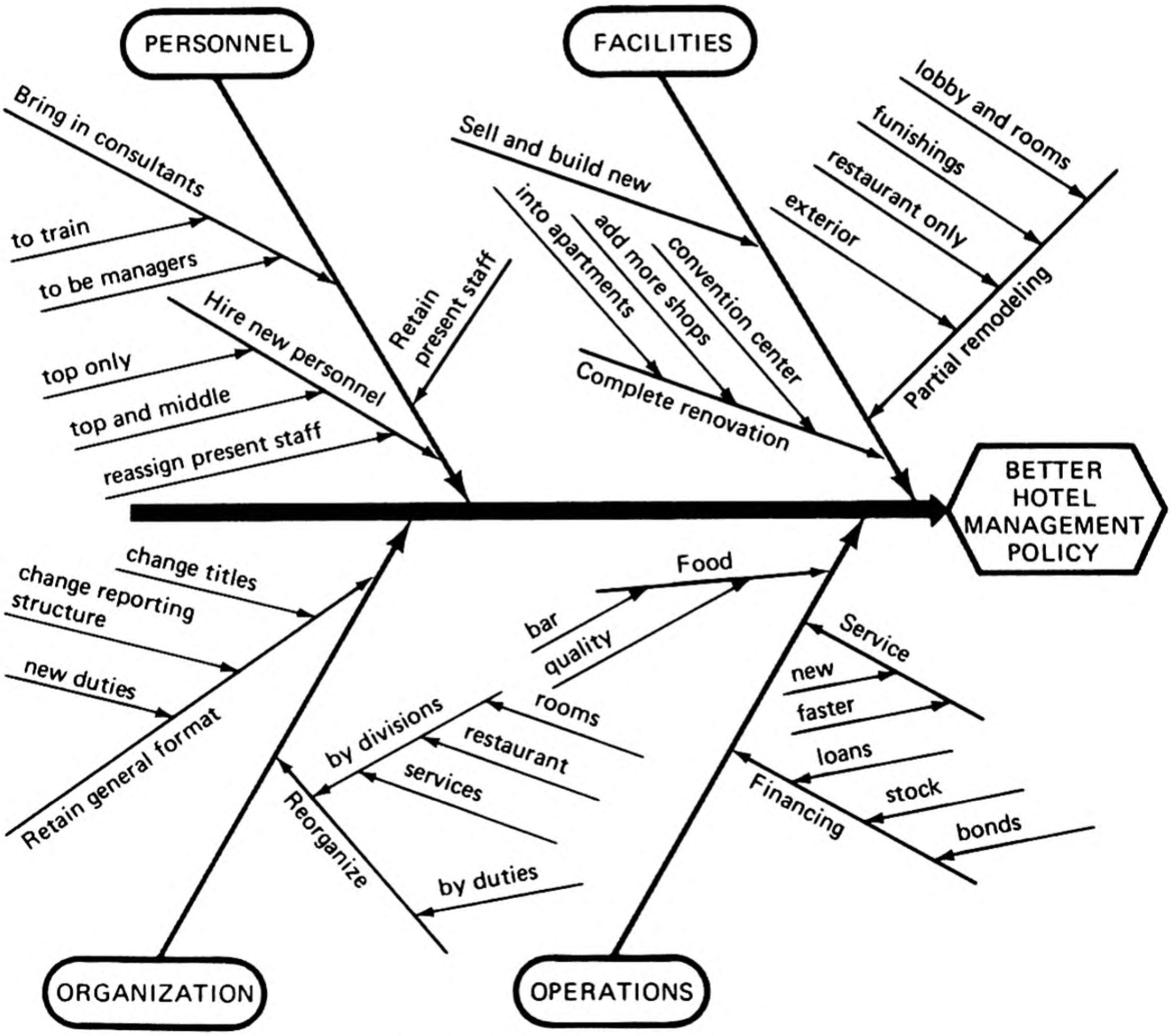

PERSONNEL
FACILITIES
Bring in consultants
to train
to be managers
Hire new personnel
top only
top and middle
reassign present staff
Retain present staff
Sell and build new
into apartments
add more shops
convention center
Complete renovation
lobby and rooms
funishings
restaurant only
exterior
Partial remodeling
BETTER HOTEL MANAGEMENT POLICY
change titles
change reporting structure
new duties
Retain general format
by divisions
rooms
restaurant
services
Reorganize
by duties
bar
quality
Food
Service
new
faster
loans
stock
bonds
Financing
ORGANIZATION
OPERATIONS

*Fig. 2-6. A cause diagram showing the problem on the right with the main factors affecting the problem in ovals. Smaller arrows indicate possible alternatives for achieving desired conditions.*

Consulting old records and personally written reports may revive useful memories. To gain the most from a list, it is advisable to rephrase each question as many times as possible until you have wrung out as many bits of knowledge as possible.

### Ideagrams

It is almost impossible to catalog ideas as they skitter through a thought chain. During a fertile period of thought, ideas erupt spontaneously, one concept building on another in a frenzy of inspiration. Ideas may come so fast that some are forgotten before they get due inspection. To preserve them for inspiration during the sterile periods that are bound to follow a lush harvest, write down your keynote notions.

A picture of a problem is developed by organizing the key aspects in a *cause diagram* (details for *cause and effect diagrams* are given on pages 48–51). The first step is to identify the main factors affecting the problem. These main causes are named and entered as ribs on the herringbone skeleton shown in Figure 2-6. Then alternatives for each main cause are attached by arrows. Little effort is devoted to evaluation of the alternatives during the inspiration phase. The main purpose of the entries is to help systemize images for later reference and inspection.

An example of idea diagraming is illustrated in Figure 2-6 where the problem is what management policy to follow in improving a recently acquired hotel. Four main causes that detract from the current hotel management are implied in ovals: incompetent personnel, inadequate physical facilities, weak organization structure, and inefficient operations. Alternatives for improvements are indicated on subarrows.

An "idea" matrix is another way to display the main features of a problem and to assist in initiation of ideas. A grid is constructed by listing problem attributes veritcally and problem resources horizontally. The intersection of each row by column factors is a source of potential ideas for a solution. Many intersections will be obviously void of ideas and be discarded immediately, but the remaining cross products may spark ideas that would otherwise pass unnoticed. A partial idea matrix for the hotel management problem treated previously is given in Figure 2-7.

More detailed versions are discussed by M. A. Allen in *Morphological Creativity* (Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962). The parameters of a problem are noted on a two- or three-dimensional matrix. Alternatives are listed for each

| | MEN | MONEY | TIME | — |
|---|---|---|---|---|
| PERSONNEL | Hire new<br>Retain old<br>Organize by teams | Initiate bonus plan | | |
| FACILITIES | Hire director<br>Get advice of consultants | Raise money by local stock sales | Stepwise vs. single renovation | |
| OPERATIONS | Build morale | Develop convention center<br>Cost reduction study | Speed-up services | |
| — | | | | |

*Fig. 2-7. An idea matrix for the hotel management problem. Row and column titles represent, respectively, attributes of the problem and resources for a solution. Each cell in the matrix may suggest ideas for alternative courses of action.*

parameter independently and are then cross-correlated to produce new ideas. The technique is especially good for product designing.

### Verbalization

A good way to get over mental blocks in idea seeking is to start talking. Everyone finds it easier to talk about doing something than to do it. It is nice to have a listener but don't make it a requirement, since it is difficult to find a listener as interested in your personal problems as yourself. A tape recording of yourself can be interesting as well as stirring. Role playing is an adaptation that can also be used individually or with company. It is an attempt to find new insights by taking the views of someone else associated with the problem. The role will always be biased by the actor's sentiments, but it may short-circuit some personal dogmas.

## GROUP IDEATION

Idea generation by a group is an example of synergistic action; the sum of the ideas from the group operating together should exceed the sum of the ideas of the individuals from the group operating on their own. The rationale is that each person's idea will stimulate a family of associated ideas among members of the group.

### Brainstorming

Brainstorming is the most famous technique for group ideation. It was originated by Alex F. Osborn as a device to increase novelty in advertising. In recent years it has been criticized because it is not the universal solver as touted by some proponents, yet it still draws its share of acclaims from practitioners.

Osborn suggests a group size of 5 to 10 people for a brainstorm, although the technique has been used successfully with groups as large as 150. Participants do not have to be experts in the problem area. But they do need to be familiar with the general subject and know the jargon of the trade. It helps to have one or two self-starters in the group to get ideas flowing, and the better the members are at letting themselves go, wildly wrapped up in the discussion, the better the session will be. Fear of looking foolish or fear of being ridiculed will scuttle a session.

The most important person for a successful brainstorm is the leader. But he should not appear important. He should not flout his knowledge or dominate the other members. Instead, after defining the scope of the problem and getting things started, he should limit his activities to keeping the topics in the general problem area and maintaining the informal interplay of ideas. He tries to keep the discussion from degenerating into an inane "bull session" or becoming too formal and restrictive.

Useful guidelines are:

1. Keep the problem as described by the leader clearly in mind.
2. Do not find fault with, or stop to explore in depth, any given idea.
3. Think freely and mention any idea, no matter how wild it is.
4. Maintain a light, humorous, even mock competitive atmosphere.
5. Encourage and support the efforts of other participants.

A productive brainstorming session should produce an idea a minute. All ideas are then recorded. After the session is over the leader consolidates ideas into natural categories and sends them to the participants for comment. He should not edit the ideas with respect to practicality because an absurd notion could spark a new, significant solution in the second go-around. Eventually the ideas must be graded. The evaluation can be done by having each participant choose a first and second choice in a follow-up meeting where several groups working on similar problems convene. The leader prepares a final summary with recommended solutions based on previous reviews.

### Synectics

The synectic technique of group ideation devised by W. J. J. Gordon[1] employs the same free-wheeling attitude of brainstorming with a different emphasis. It deals with the concepts underlying the problem situation, not the specifics of the problem itself. Since the supply of fundamentals is somewhat limited, fewer ideas are expected. The leader plays a more dominant role in the search as he seeks more depth than breadth.

A session usually begins with a thorough briefing about the problem area. However, leaders occasionally choose to begin without telling the participants exactly what problem they are investigating to avoid preconceived notions. A leader may initiate discussions by presenting an analogous situation, a demonstration, or a role-playing episode. The 5 to 10 members have been chosen for their competence in the general problem area and are expected to react with ideas after the initial presentation. These ideas will theoretically compound.

The rationale for considering basic relationships is to avoid stereotyped thinking. Exploring a familiar problem from a novel angle allows basic relationships to emerge. For example, the specific problem of how best to remove garbage might be attacked by discussing what causes wastes or any other unwanted accumulations. Analogies could be found in the physiology of animals, patterns of nature, and outputs of industry. The leader attempts to make the most promising suggestions into focal points for transition to the specific problem. He steers discussion into elaborations and analyses of key concepts. This deliberate intensity makes the synectics approach most rewarding for big-picture fundamental issues or crisis confrontations.

## PORTRAIT OF A PROBLEM

Getting started is one of the toughest parts of problem solving. In the early phases of an investigation there is an uncomfortable suspicion that not enough is known about the problem. As the investigation progresses, the source of uneasiness switches to frustrations in correlating facts and drawing meaningful interpretations from the data. Better organization of data alleviates some of the difficulties by highlighting pertinent information. Just a simple list of facts can focus attention for small problems. Analysis of larger problems is assisted by a pictorial approach that categorizes related factors to make their influence more observable. *Cause and effect diagrams* are designed to serve this function.

Cause and effect (C&E) diagrams are composed of connected arrows. Each arrow represents an important factor in the problem. The way the arrows are

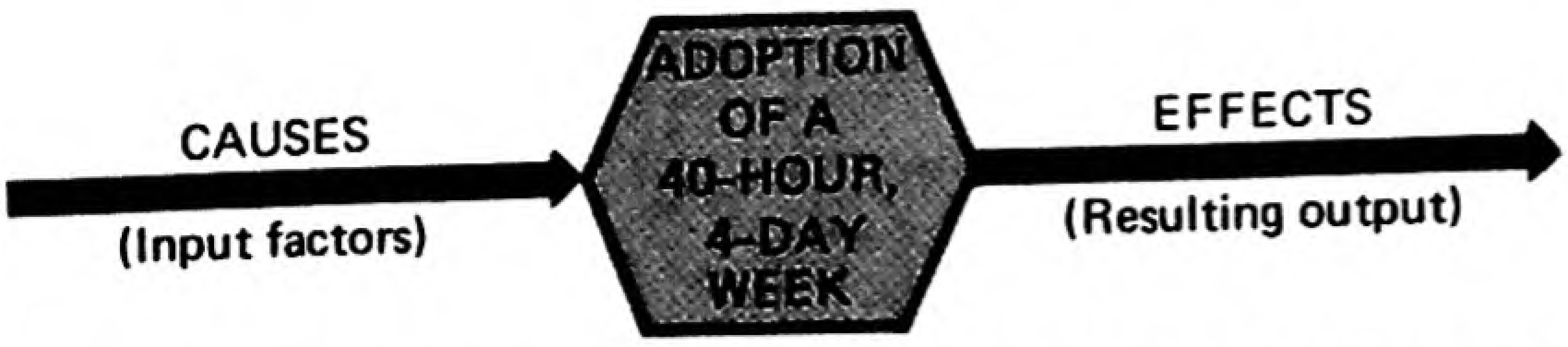

CAUSES
(Input factors)
ADOPTION OF A 40-HOUR, 4-DAY WEEK
EFFECTS
(Resulting output)

*Fig. 2-8. The first step in the construction of a C&E diagram is a statement defining the problem. To the left and right of the hexagonal statement symbol are, respectively, spinal arrows for cause and effect factors influencing the problem.*

connected shows the relationship of the factors. The inclusive or dominant factors are identified first. Then the subfactors which determine the significance of the main issues are sketched in.

### Structure and Construction

The easiest way to become familiar with C&E diagraming is to run through one. For an illustration we will return to the problem faced by the office manager described at the beginning of this chapter. His problem was to state opinions about the advisability of replacing the present 40-hour, five-day workweek by four 10-hour work days. If he organized his thoughts in a C&E diagram, he would first precisely state this problem or objective. The statement is the pivot point of the diagram as shown in Figure 2-8.

With the subject defined, the main factors are identified next and placed in ovals as in Figure 2-9. These titles represent encompassing categories. They serve the same function as headlines or chapter headings, attention getters that describe collected data.

Specific conditions of the problem are shown on the diagram by arrows attached to the titled ribs. Elaboration of successively more detailed factors creates the branching effect of the arrows. In Figure 2-10, one of the cause ribs deals with

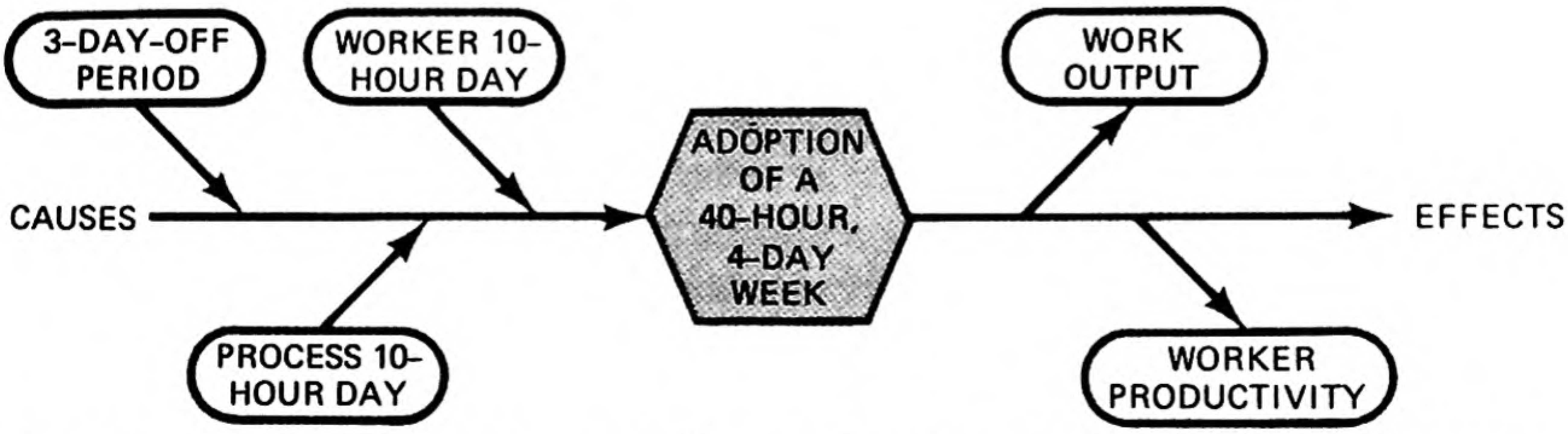

3-DAY-OFF PERIOD
WORKER 10-HOUR DAY
WORK OUTPUT
CAUSES
ADOPTION OF A 40-HOUR, 4-DAY WEEK
EFFECTS
PROCESS 10-HOUR DAY
WORKER PRODUCTIVITY

*Fig. 2-9. Main factors are shown as ribs joined to the spinal cause and effect arrows. Brief descriptions of the prime considerations are shown in ovals for easy recognition.*

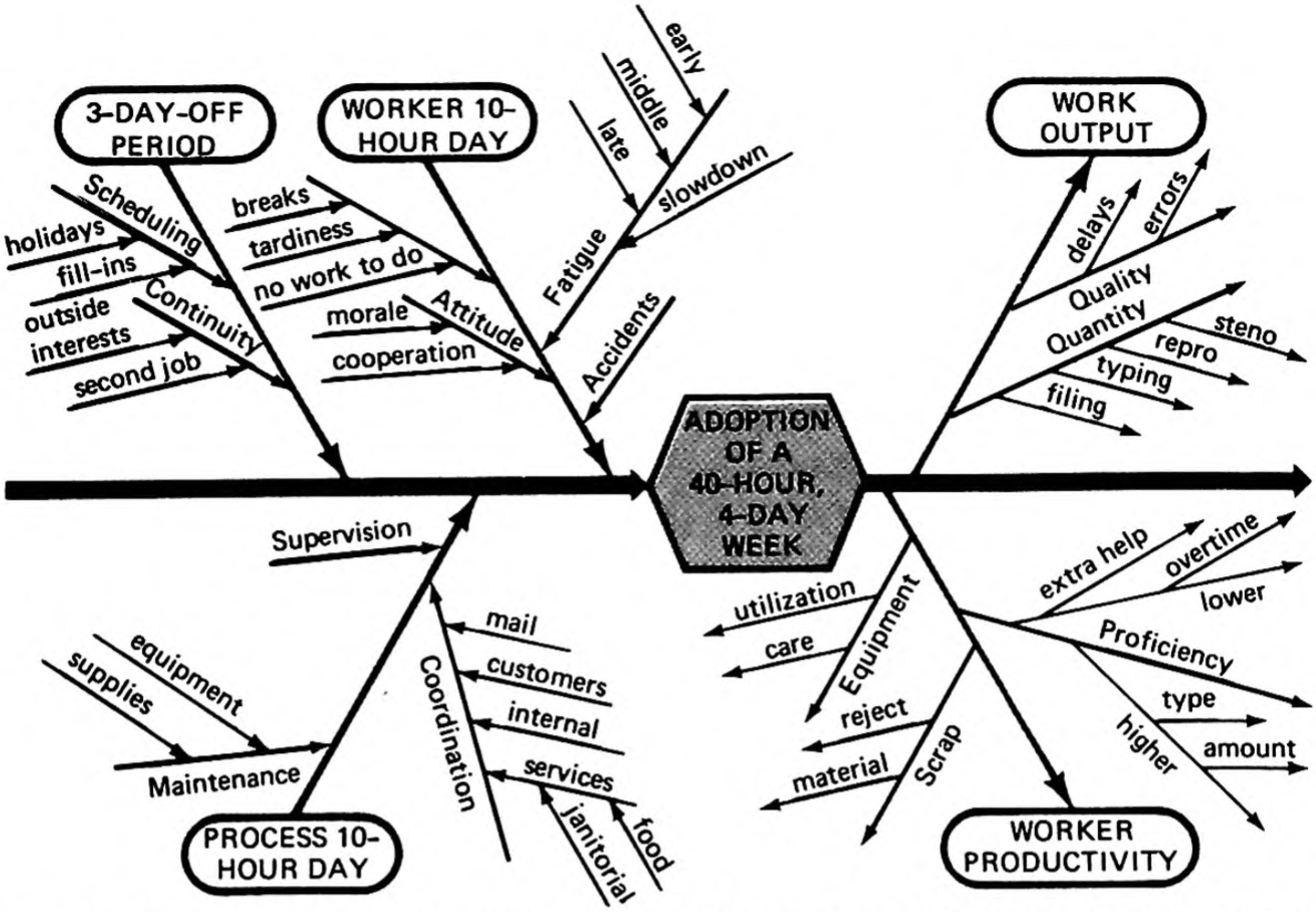

3-DAY-OFF PERIOD
Scheduling
holidays
fill-ins
Continuity
outside interests
second job
WORKER 10-HOUR DAY
breaks
tardiness
no work to do
Attitude
morale
cooperation
early
middle
late
slowdown
Fatigue
Accidents
ADOPTION OF A 40-HOUR, 4-DAY WEEK
WORK OUTPUT
delays
errors
Quality
Quantity
steno
repro
typing
filing
Supervision
equipment
supplies
Maintenance
PROCESS 10-HOUR DAY
mail
customers
internal
services
Coordination
janitorial
food
utilization
care
Equipment
reject
material
Scrap
extra help
overtime
lower
Proficiency
type
higher
amount
WORKER PRODUCTIVITY

*Fig. 2-10 Detailed cause and effect diagram of factors that might be affected if the work-week of a clerical unit were switched from 5-days, 40-hours to 4-days, 40-hours.*

the influence of a 10-hour day on the production process. One factor involved in the process is *coordination* which includes four subfactors, one of which, *services,* has two sub-subfactors, *janitorial* and *food*. The level of detail is usually extended to the point where some form of measurement can be attached. It is not always possible, of course, to put numbers on all the factors, but measurable properties are important for those subsequent evaluations that select the preferred solution.

### Variations and Interpretation

Early users of interlocking arrows to portray problem conditions typically concentrated on just one side of a C&E diagram. The Ishikawa diagram, named after its originator,[2] is widely used in Japan to show the causes of a quality control problem. Professor Kaoru Ishikawa first used the arrow format for cause analysis (Tokusei-Yoin Hyo) while conducting quality control studies for the Kawasaki Steel Company in 1953. A one-sided diagram was used in Figure 2-6 to display factors contributing to a better hotel management policy. In a similar fashion, an effect diagram could portray the possible results of a new policy.

Cause and effect diagrams are useful for both individual and group ideation. A cluster structure based on a familiar sequence of events is a convenient pattern for solo investigations. A cluster of factors is developed around each of the oval headed main ribs. These ribs are ordered in the typical time sequence of occurrence associated with the particular problem; for instance, a material flow process might have sequential ribs labeled *purchase, receive, store,* and *transport.*

A C&E format can be used to record the ideas generated in group problem-solving sessions, especially for directed discussions like the synectic technique. Capturing and organizing ideas by connected arrows may inhibit a free-wheeling brainstorming session, but it can reveal relationships that might otherwise have escaped detection.

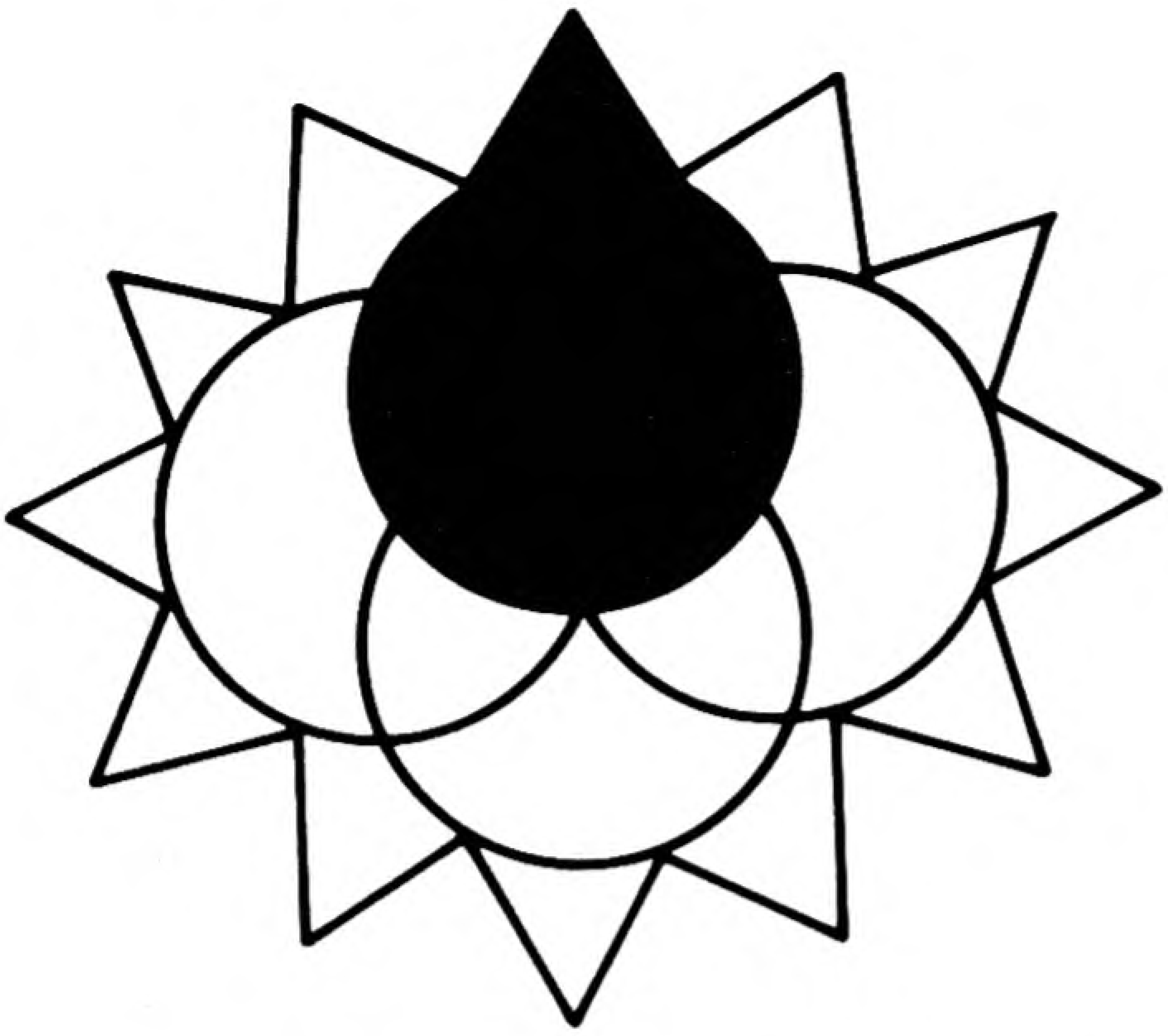
Another aspect of C&E diagraming is the ease with which the quality of the diagram can be assessed. A reviewer can easily tell how thoroughly a problem was probed by the pattern of its C&E portrait. A wealth of detail, if legitimate, indicates an exhaustive effort. A bare skeleton means either the problem was negligible or the solver was negligent.

In many ways the C&E diagram epitomizes the difficulties of investigating. The diagram can take as many forms as can investigations. Each individual has his preferred version. The general C&E format is applicable to any problem just as other concepts and techniques for investigation can assist any search. Each practitioner adapts diagrams, concepts, and techniques to his own style, some more effectively than others. And, most important, there is no way the construction of a C&E diagram can guarantee the solution to a problem; similarly, there is no single best way to search for answers. A solution may be revealed to one person by a diagram or a technique while the same answer goes undetected by another person. Finally, a person becomes more accomplished after using several C&E diagrams, and he becomes a better investigator after participating in several investigations.

## REFERENCES

1. W. J. J. Gordon, *Synectics,* Harper & Brothers, New York, 1961.
2. Other versions of C&E charting are discussed in M. S. Inoue and J. L. Riggs' "Describe Your System with Cause and Effect Diagrams," *Industrial Engineering,* April 1971.

# Chapter 3



# Organizing

**KEY SUBJECTS**

*Personal and group organizing relies on systematic planning and actions.* An individual must develop an orderly approach for his own performance before he can organize group activities. Coordination of activities requires knowledge of what to expect when, what current capabilities are, and what has already been accomplished.

*An organization is designed to coordinate material and human resources, minimize conflict, and provide effective communications.* The design should recognize special skills of workers and the benefits possible from departmentalization. Organizations are commonly divided into internal or external services provided and into internal or external functions performed.

*The arrangement of line and staff functions establishes authority-responsibility and subordinate-supervisor relationships.* Authority is associated with a position held, but to be effective it must be earned by respect from subordinates. Staff positions which support line activities have functional authority. Responsibility accompanies authority and is owed to the source from which the authority was delegated. The unity of command principle suggests each subordinate should have only one supervisor. The supervisor to subordinate ratio is set by deciding what span of control is appropriate at each management level, a decision affected by many factors.

*Most organizations can be represented by a triangular pattern that shows a decreasing number of employees at each higher level of authority.* Upper levels are characterized by longer planning horizons, greater freedom of action, and a wider range of events to consider. Steeper triangular patterns are associated with more centralized decision-making powers, longer lines of communication, and a narrower span of control. A rectangular pattern is occasionally useful to give distinction to unique projects or products.

*Formal relationships in an organization are supplemented by committees and a grapevine.* Committees can perform useful functions when properly conducted, and they can be wasteful when overused or abused. The grapevine, an almost unavoidable spontaneous communication circuit, cannot be controlled but deserves vigilance.

## INDIVIDUAL ORGANIZING

Everyone has to organize at least a little bit. Some do it far better than others. If a person does not organize well, he can suffer some ill effects. First, people frown because his surroundings are so messy. Then, they look upon him as a type of Don Quixote who gallops off on "wild goose chases" and is forever engaged in frantic, fanciful, and futile actions. In spite of this tendency to rush off in too many directions at one time, the disorganized person may get along reasonably well. Think, however, how successful he could be if he did coordinate and direct his efforts.

One trait of disorganization is very common—procrastination. Even efficient managers fall prey to the temptation to "put it off." Norman Vincent Peale tells the story of how he watched a man behind the information desk at Grand Central Station keep his cool while people clamored for his services. He would pick out one person from the crowd, look directly at him, and answer his question slowly and deliberately. He never shifted his eyes nor paid attention to anyone else until he was finished. Then he would single out the next questioner. When asked how he retained his poise he answered, "I've learned to focus on one person at a time and to stick with his problem until it's settled. Otherwise, I'd go mad."[1]

This success story suggests the importance of setting priorities for issues and then focusing on one at a time until it is satisfied. The story also implies self-imposed deadlines and enough discipline to avoid ducking issues. *How* you set priorities and fulfill them depends upon yourself. For example, you might (even mentally) make a list of jobs to be done. As each job is done, you cross it off and enjoy a satisfied feeling of accomplishment.

Individual organizing is frustrated by too many personal hangups to treat each one in print. Instead, we will consider principles of organization that apply to both personal and interpersonal organizing activities. As a start, to relate larger organizational problems to more personal problems of individual organizing, we can observe how organizing duties change as an enterprise evolves from a one-man to a multi-man operation.

The operator of a one-man shoe-repair service has to organize his activities every day. Time must be allocated for customer contacts, repair work, and support duties such as securing materials, maintenance, and bookkeeping. The operator cannot allot too much time to any one activity because neglect of others can ruin his overall output. Still, some duties are more important than others. Such critical concerns deserve close attention and detailed organizing.

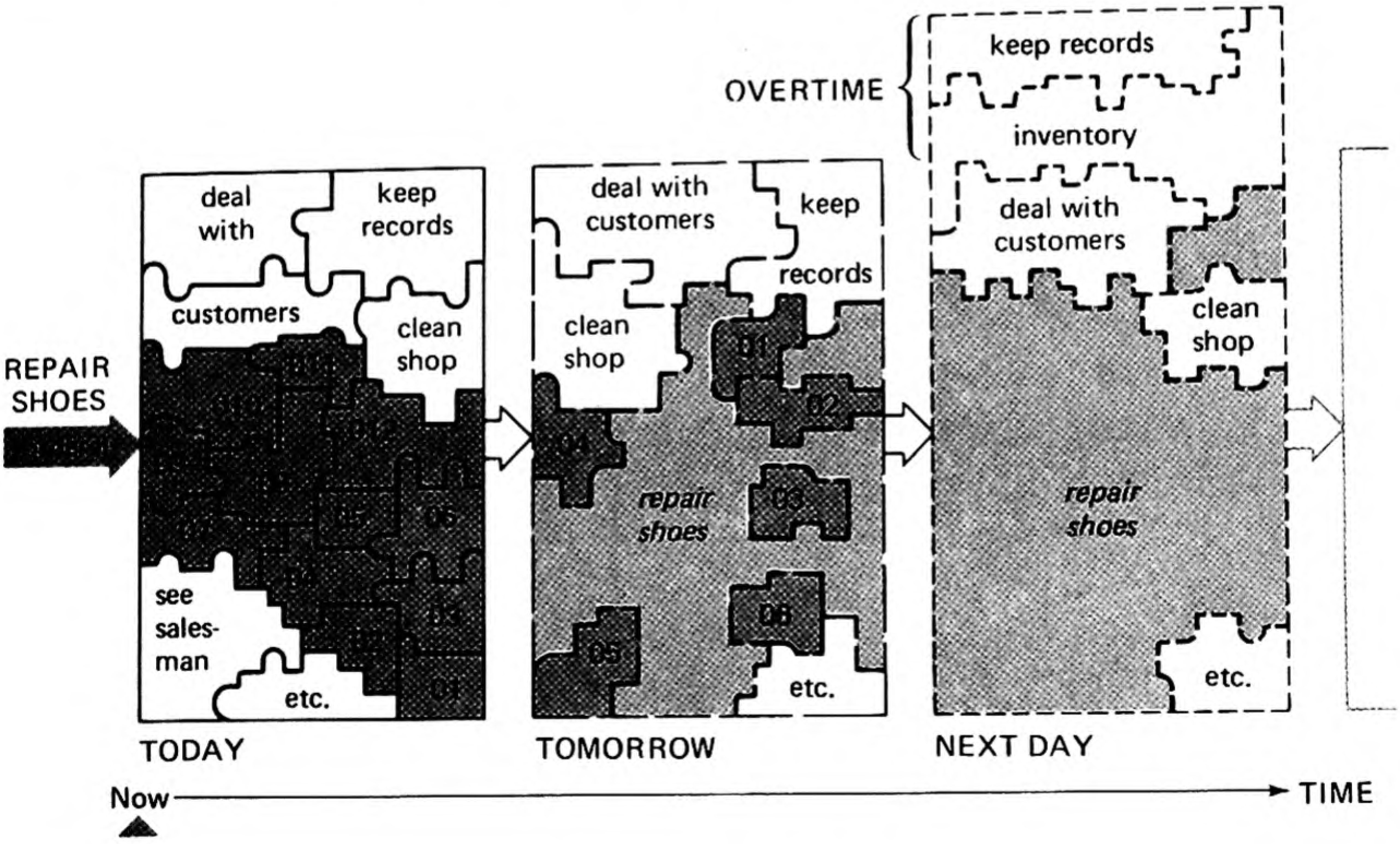

OVERTIME
keep records
inventory
deal with customers
clean shop
repair shoes
etc.
REPAIR SHOES
deal with
keep records
customers
clean shop
see sales-man
etc.
deal with customers
keep
records
clean shop
01
02
03
04
05
06
repair shoes
etc.
TODAY
TOMORROW
NEXT DAY
Now
TIME

*Fig. 3-1. Organizing activities for a one-man shoe-repair service. Each day expected accomplishments have to be fitted to available time. Some advance organizing should be done to confirm current priorities. When demands exceed resources, extra resources such as overtime must be provided or the demands reduced.*

A competent organizer knows which demands are more pressing. If the shoe repairman has built his reputation on speed, he knows promptness is vital. However, if he wants to create an image of low cost, an unusual specialty, or customized service, he organizes differently. The repairman should keep in mind what to expect when, what his own capabilities are, and what has been accomplished.

As pictured in Figure 3-1, organizing a day's work is like fitting a picture puzzle together where the pieces are activities and the total picture is the day's work. In the *today* frame, the activity *repair shoes* is broken down into exact orders to fulfill. Subsequent days' activities cannot be organized as specifically because exact orders are not yet available. However, as unfilled orders build up a backlog of work, the need for a catch-up period can be anticipated several days in advance. Organizing involves arranging for immediate activities and relating these to future activities.

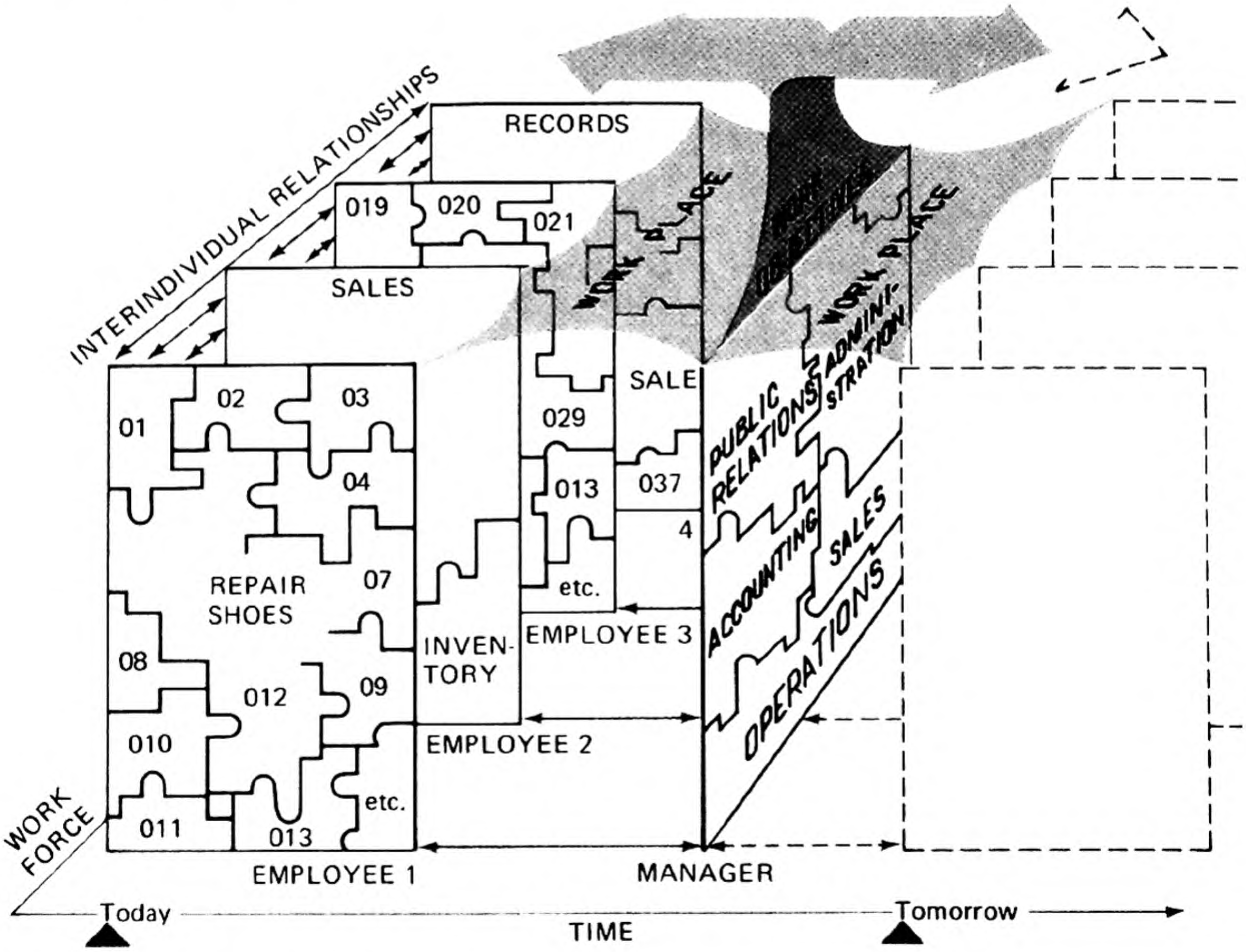

INTERINDIVIDUAL RELATIONSHIPS
RECORDS
019
020
021
SALES
01
02
03
04
REPAIR SHOES
07
08
012
09
010
011
013
etc.
WORK FORCE
EMPLOYEE 1
INVEN-TORY
EMPLOYEE 2
029
013
037
etc.
SALE
4
EMPLOYEE 3
MANAGER
WORK PLACE
WORK PLACE
PUBLIC RELATIONS
ADMINI-STRATION
ACCOUNTING
SALES
OPERATIONS
Today
TIME
Tomorrow

*Fig. 3-2. Organizing activities for a multiman shoe-service company. The manager coordinates the activities of the work force with respect to the workplace to accomplish the work objectives. As long as the company remains small, the manager can organize interindividual activities on a daily basis and still arrange his own activities to accommodate support functions.*

## SMALL-GROUP ORGANIZING

Let us assume our shoe repairman was a whiz at organizing and successfully expanded his business to include the services of several repairmen plus retail shoe salesmen. He still organizes, only his scope of organization has enlarged. He still knows what to expect when, what his company's capabilities are, and what has been done, but he does not know it as well as when he did everything himself. In addition, he has extra things to organize, a longer time span to consider, and more chances for his organizational efforts to be misunderstood.

Figure 3-2 displays some of the organizational complications that occur as an enterprise becomes larger. A manager has to organize his personal activities in order to organize the activities of others. Then he has to present his plan of activities to his employees and get from them the progress made on plans previously submitted. These progress reports should influence his own organizing efforts, and he should recognize how each worker's activities affect other workers and ultimately affect productivity. Finally, the manager seeks to combine all current considerations with his interpretation of future conditions to help organize impending activities.

Imagine the above complex interrelated pattern in a large business; it becomes evident that organizing can be an overwhelming chore. Although organizational patterns and policies have evolved over the years to relieve some complexities, the basic task of an organizer is still to organize his organization.

## FOUNDATIONS OF ORGANIZATION

The shoe shop, General Motors Corporation, and the Federal Bureau of Investigation are called *organizations.* For example, when someone refers to *that organization*—meaning a specific institution such as GM—he refers to the corporation as a whole. But when he speaks of the *organization of GM,* he means the structure of the institution. Both meanings are used in business with little confusion, and they imply a two-part definition for the *organizing function.*

1. The process of developing effective relationships between workers, workplace, and work objectives.
2. The arrangement of a structural framework to facilitate administrative and operational goals.

The two parts are intimately linked. A good structure is vital for effective performance of individuals, and sound individual relationships are necessary before the structure can produce the desired output.

Organizing is undertaken to allocate activities needed to accomplish something. Regardless of the size of the organization, three criteria should be satisfied.

1. *Coordination of material and human resources*—people should understand the function they are to perform and possess the physical resources needed for performance.
2. *Minimum conflict of objectives between organizational units*—coordinated objectives avoid duplication of effort and encourage cooperation.
3. *Effective two-way lines of communication throughout the organization*—word passes quickly and accurately on what is to be done and what has been accomplished.

It is doubtful that an organization has ever accomplished all three criteria perfectly. Agreement is lacking on the best ways to approach the ideal, or even what is an ideal organizational design. Since there is no guaranteed recipe to follow, we will study the ingredients and leave the mixing to each management artist.

### Specialization or Despecialization

There have always been specialists. By ceremonial rites, through training, or via unique talents, individuals became experts in certain pursuits. Skills were passed from father to son to perpetuate distinctions. Guilds were formed in the Middle Ages as group efforts to protect select craftsmen. Since the industrial revolution, specialization of labor has departed from the concept of individual craftsmanship to become a vehicle for mass employment of special skills.

In a modern industrial setting it would be ridiculous to expect one individual to perform efficiently all the tasks necessary to produce a product. Too many jobs require specific experience. In theory, workers could easily be trained as specialists in a limited number of movements, and in theory the sum of individual proficiencies would lead to a high level of efficiency. A narrow skill content for jobs also tends to make worker replacement easier and consequently has the effect of keeping wages low.

The trend toward ever more specialization for factory workers started to be questioned in the 1930s and 1940s. By then some job contents were so narrow that they involved only turning a nut on passing frames or dabbing the same spot of paint on a procession of parts. Studies found that workers were bored and dissatisfied.[2] Many workers were "turned off" by mechanical pacing, repetition, and a feeling that they accomplished nothing. As a result, their production went down. It became necessary to see if overspecialization was worth it.

Several schemes for limited widening of work content in standard jobs have been introduced. Studies suggest that implementing *job enlargement* can improve worker morale, promote quality, and reduce costs of supervision.[3] Job enlargement is accomplished by restructuring jobs to include more variety of tasks; instead of performing three simple operations, a worker might be assigned seven operations at his work station under the assumption that greater variety makes the same job less dull. Another method designed to increase interest is *job rotation,* periodically swapping jobs among workers. Other methods relying on the participation of the operators to help design their own work have been experimented with, some going beyond job design to include promotion, salary, and other financial features.

Attempts to despecialize jobs are still underway. While many specialized jobs are exempt due to union rulings, long training time required, or technological limitations, current social pressures are forcing managers to take a close look at task groupings. Modern workers want their jobs to be interesting, and they are more vocal than previous generations in voicing their complaints. Managers should listen because discontented employees are expensive. The cost advantages from specialization can be lost to poor overall efficiency of the work force. The problem is to determine what level of specialization (or despecialization from existing patterns) produces the greatest productivity from a labor pool that has growing expectations about the nature of its labor.

### Centralization or Decentralization

The organizational question of centralization is related to problems of worker specialization. Instead of focusing on the tasks grouped to form jobs for individual workers, centralization involves the grouping of jobs. Basically, centralization is the concept of specialization applied to managerial pursuits.

Beneath the surface applications of grouping designs lies the core issue of control. Despecialization and decentralization decrease control by higher management levels, with the result that more decisions are made at lower levels. Consider two parallel examples to illustrate the relationships.

**DESPECIALIZATION.** One phase in the manufacturing of toy dolls involves an assembly line where plastic torso parts of a doll are joined, clothed, and then inserted in a gilded cardboard frame for packaging. Assemblers originally specialized in a single operation such as attaching arms and legs or fitting dresses on the body. Despecialization changed the work content to include all the operations from joining parts to framing. Each worker became responsible for inspection of parts being assembled and the quality of the finished product. More job variety was introduced at the expense of control over individual phases of the process.

**DECENTRALIZATION.** A chain of quick-lunch restaurants had outlets in several states. The original organization provided centralized purchasing, accounting, advertising, personnel training, and standard operating procedures for each establishment. The restaurant manager handled only coordination and day-to-day scheduling. Decentralization was instituted to make the branches more responsive to local conditions. Most supplies and promotion material still came from the headquarters, but each manager became responsible for his own hiring, ordering, accounting, and general operations. In effect, some authority and responsibility for decisions shifted from headquarters to individual managers.

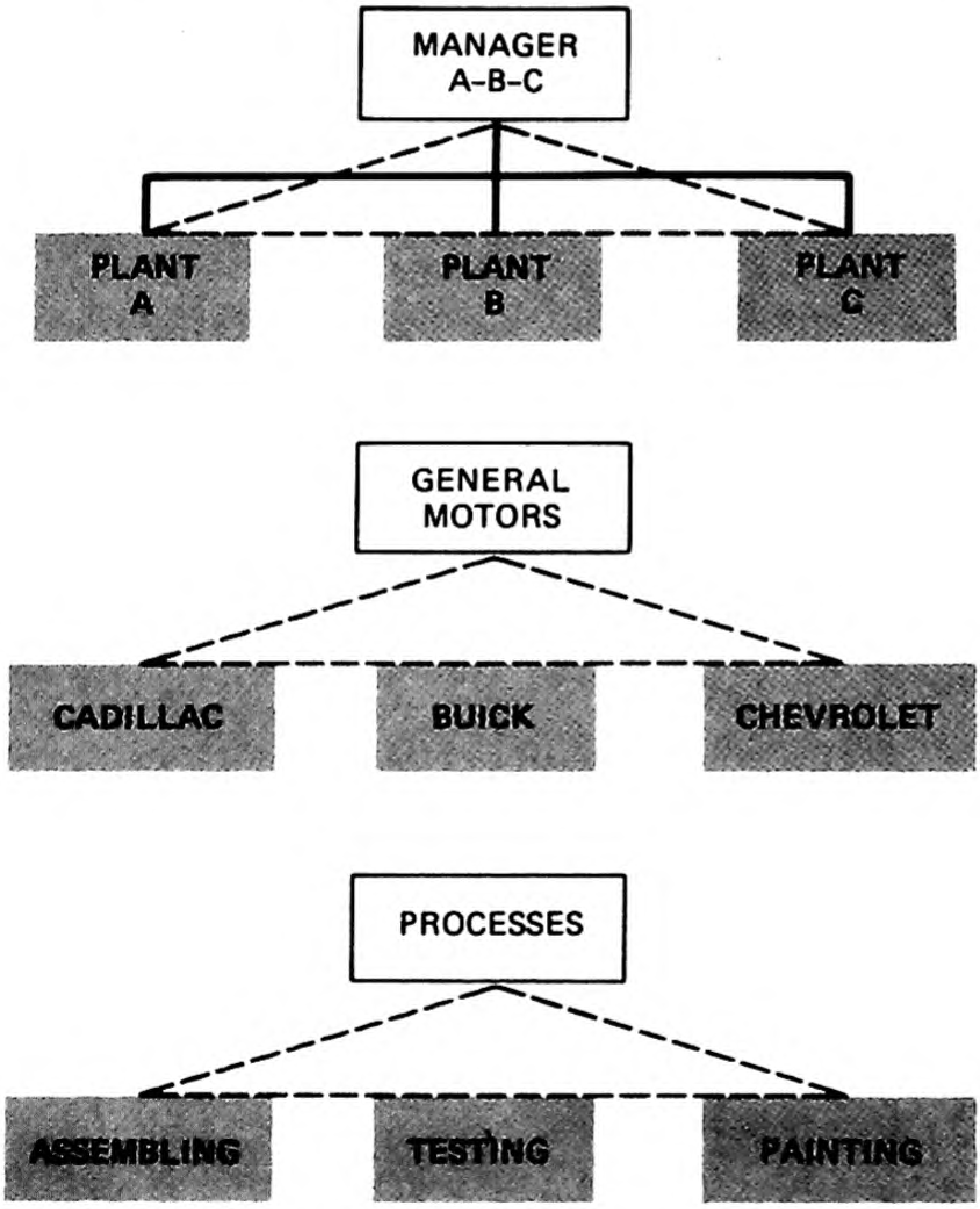
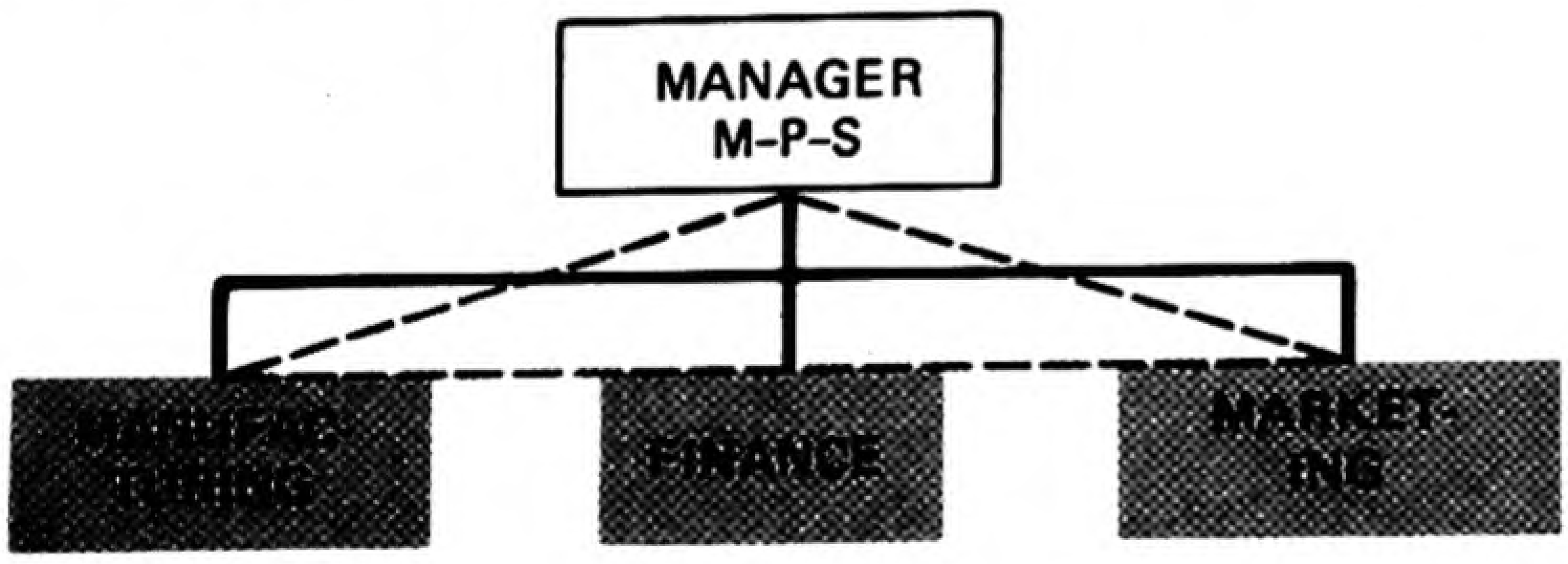


*Fig. 3-3. Division by internal services. Growth in an organization frequently stems from the introduction of new plants, products, or processes, which results in the creation of new divisions. Such divisions, which group together people with specialized skills or experience affiliated with the particular new function, may be added without greatly disturbing the existing arrangement.*

To have more or less decentralization is a sticky question, one with logic and supporters for each way. Traditional growth of an enterprise centers around a strong individual or core of individuals. The founders build their growth on personal initiative and expertise. While expanding, they typically keep control of the key functions to make all operations responsive to their directions. Such personal control is earned at the expense of inundation by details. The accumulation of minutia harasses the founders and deprives them of time needed for essential decisions. At least partial decentralization is necessary for survival.

How much decentralization depends on the nature of the business, competence of the personnel, and the philosophy of the executives at the top. Some enterprises such as technical sales and services are run most effectively by having all customer contacts funneled through a central office. Occasionally, for instance in some developing countries, not enough adequately trained managers are available to staff a decentralized network. The leaders of an organization may feel that a concentrated command can react faster to major crises, avoid duplication of effort, and provide more coordinated guidance. Opposing arguments rest on beliefs that a decentralized organization produces decisions more sensitive to local demands, gives broader experience to managers, and motivates them by throwing them into open competition with one another.

Decentralization tends to push decision-making authority downward. As practiced by individual managers, it means subdividing work and giving subordinates the authority to conduct the assigned work. In an enterprise, it often takes the form of departmentalization. Several designs are pictured in Figures 3-3 to 3-6.



**Other functional divisions:**

**DISTRIBUTION**
**EMPLOYEE RELATIONS**
**PURCHASING**
**RESEARCH AND DEVELOPMENT**

*Fig. 3-4. Division by internal function. Departmentalization according to groups, each performing one function for the whole organization, is a traditional design. Functional divisions are often used for subdividing larger departments; for example, a production department could be divided into groups for production control, inventory control, quality control, etc.*

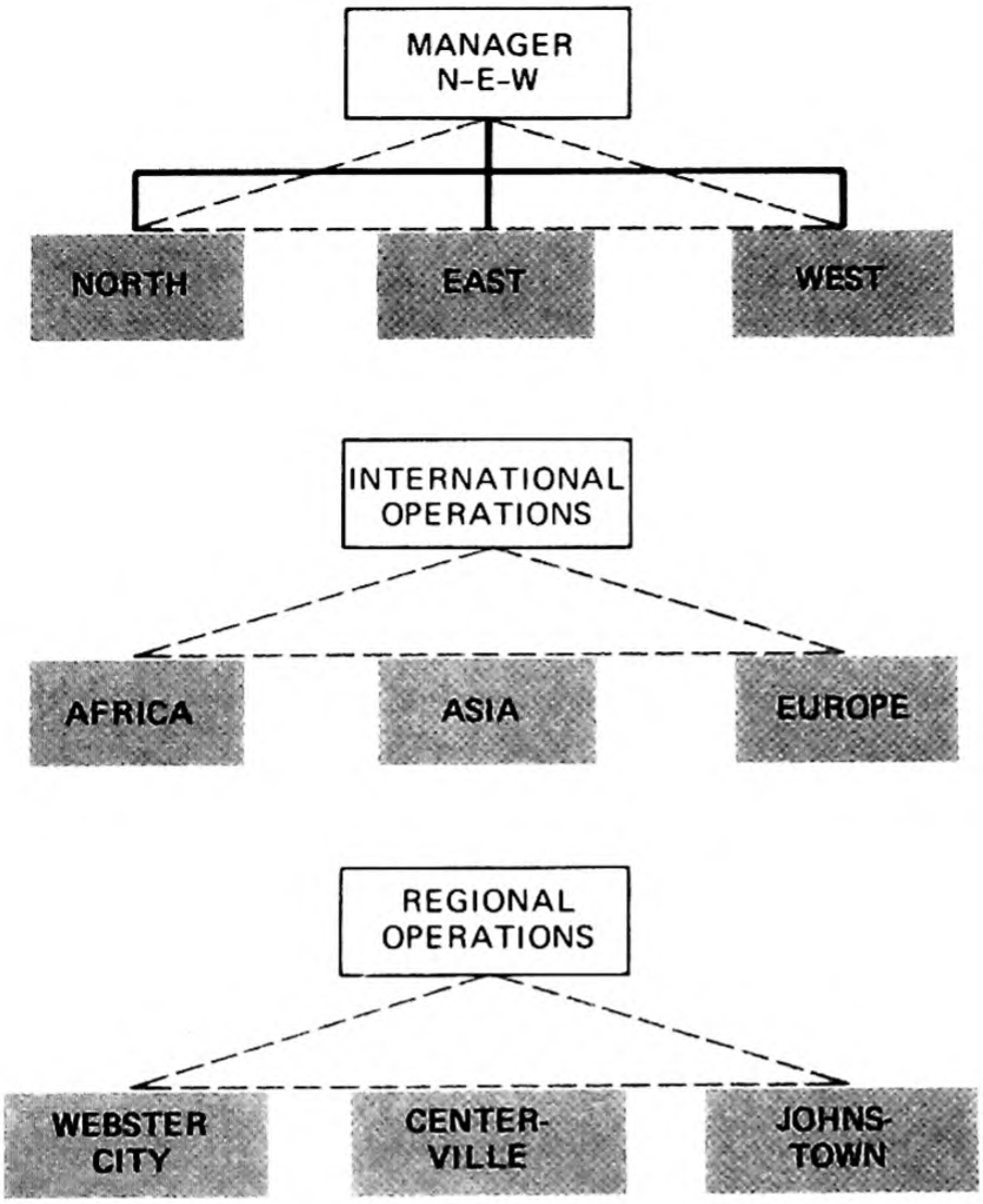

MANAGER N-E-W
NORTH
EAST
WEST
INTERNATIONAL OPERATIONS
AFRICA
ASIA
EUROPE
REGIONAL OPERATIONS
WEBSTER CITY
CENTER-VILLE
JOHNS-TOWN

*Fig. 3-5. Division by external services. Hotel chains, retail distributorships, utility companies, and other "stretched-out" companies find it convenient to group operations according to location. Major executives are frequently in charge of an area which is further subdivided by internal functions and services. Advantages of departmentalization by area include familiarity with unique conditions in different geographic locations and quick response to changes in local situations.*

Note that greater departmentalization actually causes decentralization only if authority to make decisions accompanies the redivision of operations.

Most large enterprises employ a combination of the described organizational designs along with other forms of departmentalization suited to their unique situations. A combination design is shown in Figure 3-7. It is but one of innumerable possible permutations. The right design coordinates operations without destroying initiative and allows depth of specialization while maintaining breadth of service.

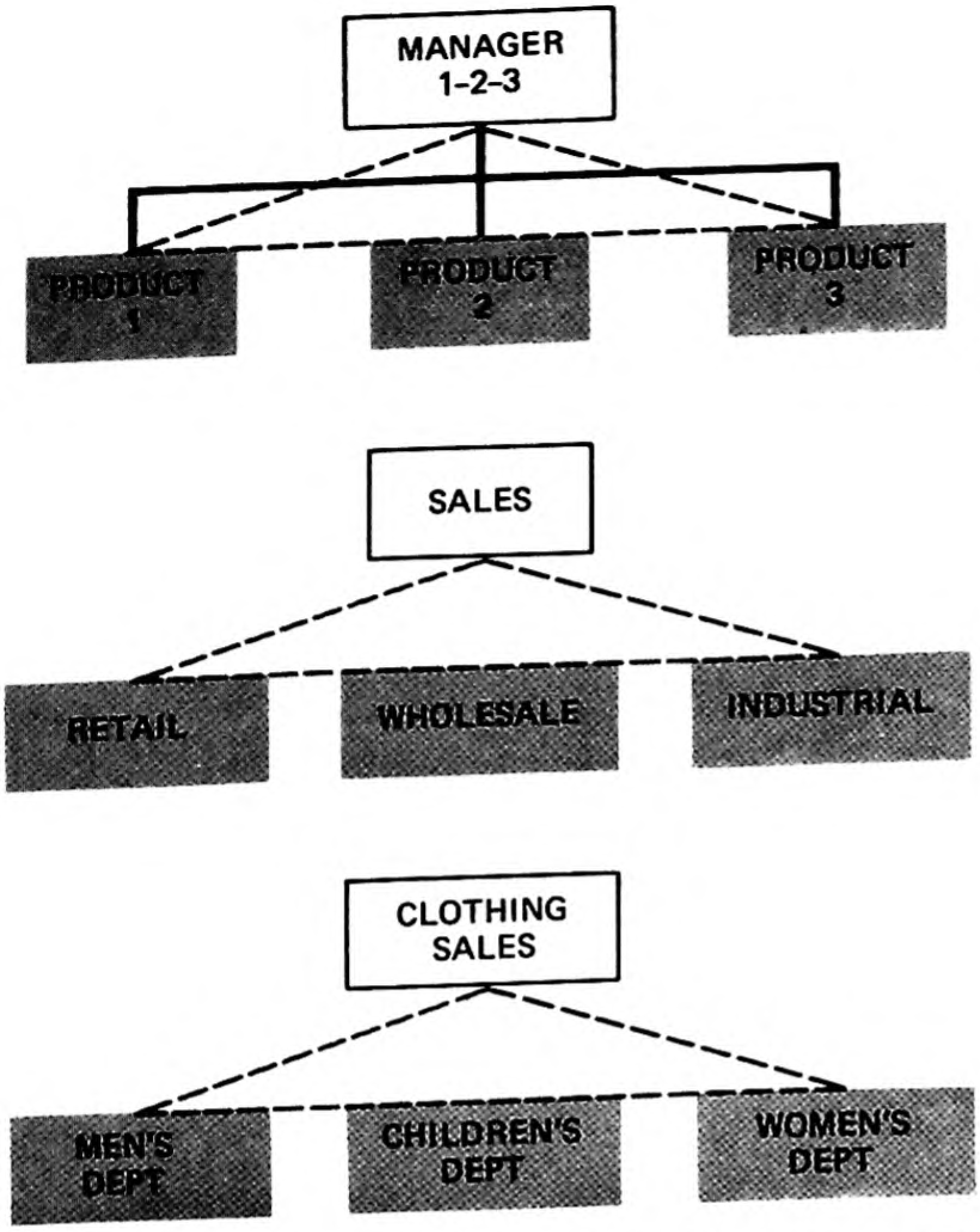

MANAGER 1-2-3
PRODUCT 1
PRODUCT 2
PRODUCT 3
SALES
RETAIL
WHOLESALE
INDUSTRIAL
CLOTHING SALES
MEN'S DEPT
CHILDREN'S DEPT
WOMEN'S DEPT

*Fig. 3-6. Division by external functions. Companies with a strong sales orientation often use customer classes for their organizational divisions. By grouping personnel according to clients, a company emphasizes specialized knowledge of customers' needs and wants. Subdividing other divisions by external functions can be a convenient way to delineate areas with similar characteristics.*

### Line and Staff

Theory on more or less specialization and centralization eventually takes the form of fine-print specifics of what people are expected to do. These specifics are the bases for line and staff relationships. As a basic definition of the relationship, *line* refers to actual operations that lead to an output, while *staff* is considered an advisory function for the line. In practice, line and staff functions are not so easily categorized.

**LINE ORGANIZATION.** Military and religious organizations have preserved the classic line organization down through history. Many parts of this form of organi-

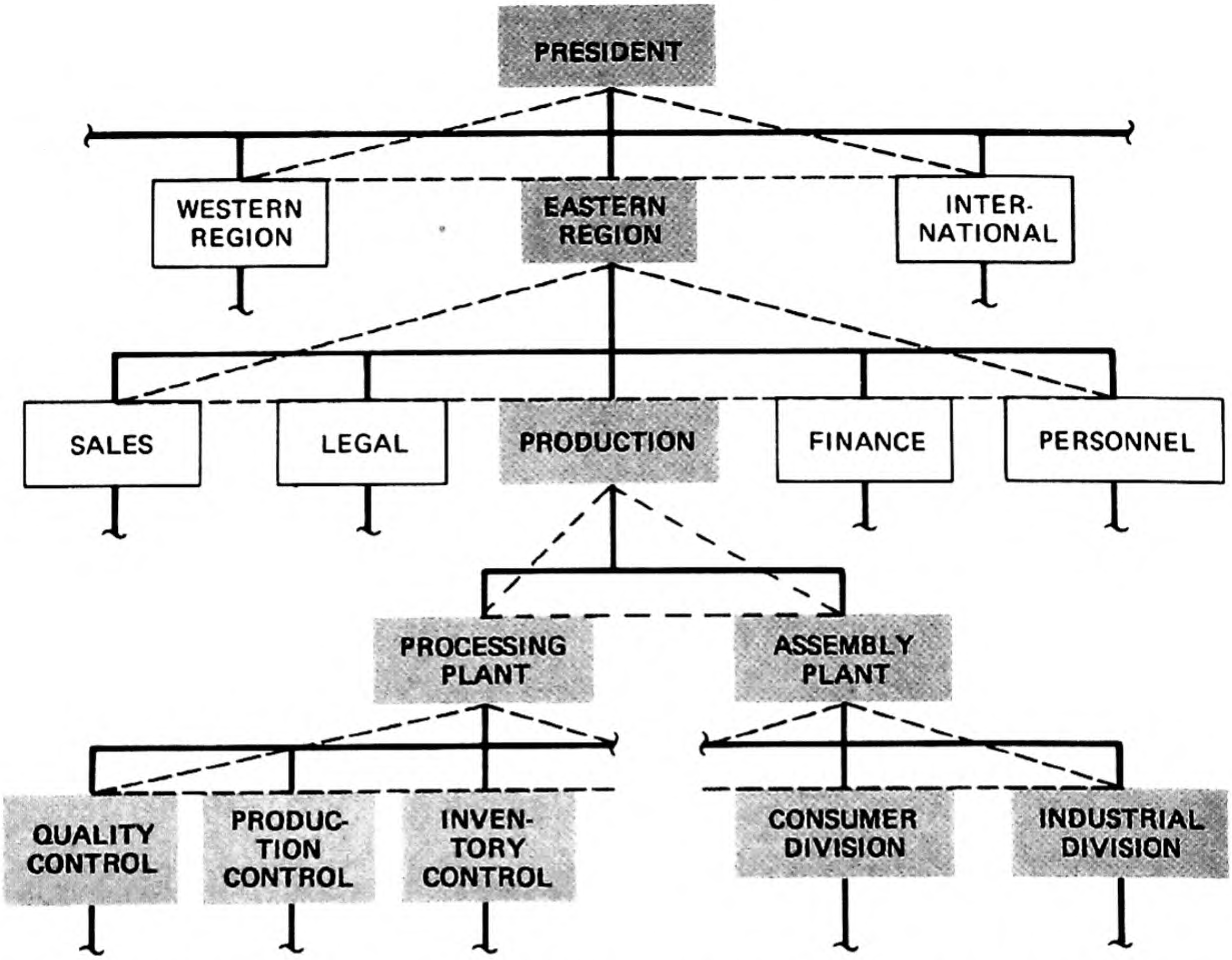

PRESIDENT
WESTERN REGION
EASTERN REGION
INTER-NATIONAL
SALES
LEGAL
PRODUCTION
FINANCE
PERSONNEL
PROCESSING PLANT
ASSEMBLY PLANT
QUALITY CONTROL
PRODUCTION CONTROL
INVENTORY CONTROL
CONSUMER DIVISION
INDUSTRIAL DIVISION

*Fig. 3-7. Portion of an organization chart for a multinational, multiplant enterprise showing divisions by subject area. Actual organizational charts are much more detailed and, of course, show titles for managers at each level.*

zation are still appropriate today, especially for smaller enterprises. It is difficult to dispute the classic beliefs that each worker should have a single boss and that an order to do something should be accompanied by the power to get it done. However, strict reliance on such beliefs can produce awkward situations in larger organizations. Although different concepts about line-staff relations abound, the classic structure remains in various forms.

*Unity of command* is a respected principle of organization. In Chapter 1 the principle was illustrated with communication difficulties; strict enforcement of a rule that each subordinate should communicate with one supervisor would not allow information flow between subordinates. The need to bypass formal one-to-one correspondence has long been apparent and many shortcuts have been explored. An important point is that the unity of command principle helps to distinguish between line and staff. Members of the chain of command directly responsible for accomplishing the organization's objectives are *line personnel.*

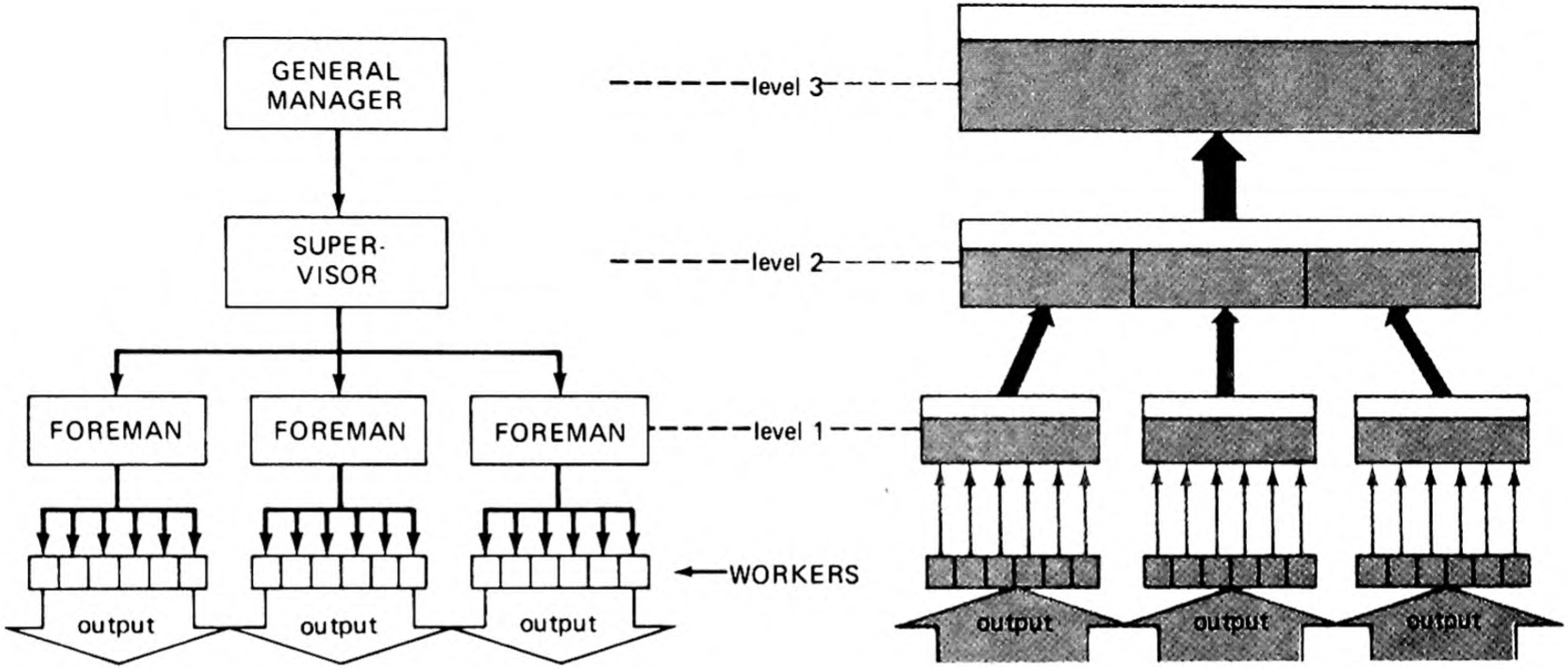
The connection between responsibility and authority is another principle of management. When a supervisor assigns duties to a subordinate, he should realize he has to delegate the authority needed to get the work done. In turn, the subordinate should recognize that he is responsible to the supervisor for performance of the assigned duties. Both viewpoints normally appear reasonable, but occasionally conditions occur that place the obvious in doubt.

A manager who has built his company from scratch is apt to find it difficult to delegate authority. He is reluctant to admit anyone else knows enough about his company to do the job as well as he could do it. At the other extreme is a position of authority filled by an individual who lacks the respect of subordinates. He may have trouble delegating some of his *positional authority* because subordinates do not trust him; he lacks *earned authority*. Positional responsibility is another thorny issue. Authority can be assigned to a subordinate position, responsibility cannot. As portrayed in Figure 3-8, responsibility is owed to the next higher echelon, while tasks are delegated to the next lower echelon. Delegating duties, actually sharing authority to conduct duties, does not relieve the upper position from the obligation to see that they are done.

**STAFF ORGANIZATION.** Staff positions are created to obtain benefits of specialized skill and individual talents. Staff personnel provide service to the line personnel by applying their expertise to line problems, by relieving line managers of detail and paperwork, and by preparing plans for innovations or modifications that affect one or several line operations. For example, a legal officer advises what a firm should do when legal questions arise from operations, and a market research staff does marketing studies which may influence the scheduling and operations in several line departments.

The size and composition of staffing vary with its position and purpose in the total organization. A marketing specialist might be hired to assist the president of a small, growing company. With growth of the company, the single marketing job could enlarge to a whole department that would still be essentially an advising agency. More commonly, staff positions are associated with a certain line position and serve the line according to the responsibility and authority of the line manager involved.

Subordinate staff positions are endowed by the affiliated line position with *functional authority*. Where line authority carried the right to take action, functional authority may only indicate the way something is to be done, but have no power to get it done. This authority can cut across departmental lines and move through


GENERAL MANAGER
SUPER-VISOR
FOREMAN
FOREMAN
FOREMAN
level 3
level 2
level 1
WORKERS
output
output
output
output
output
output

UNITY OF COMMAND: Each worker has one supervisor from whom he receives his commands. Arrows show the direction of duty assignments and, in reverse, the routes for reporting accomplishments.

AUTHORITY-RESPONSIBILITY: Units of output are level-of-accomplishment responsibilities. Support responsibilities are added at each higher level. The same segments in a reverse flow represent authority.

*Fig. 3-8. Schematic and symbolic line organization depicting chain of command, delegation of authority, and accumulation of responsibility.*

different echelons of command. Such encompassing influence, coupled with sketchy limits on jurisdiction, often leads to friction between line and staff.

A staff specialist may work so narrowly within the area of specialization that his grasp of the entire operation is weak. His lack of vision could then lead to suggestions that are technologically appealing but economically impractical. Staff units are also highly susceptible to empire building (enlarging one's staff or one's responsibilities). Two forms are common. One is the addition of more members to a staff unit without a corresponding increase in the unit's responsibility. The other (a potentially more damaging form) is the assumption of line functions without authority. The first condition could be caused by a staff head's feeling that building a larger group will make him and his staff more important. The second condition could result from a staff member's feeling that his position is out of the mainstream of activity. Countermeasures to such staff difficulties are more precisely stated objectives, defined boundaries of activity, known limits of authority, and recognition given for the employment of specialized skills.

### Subordinate and Supervisor

Considerations of accountability, specialization, and line-staff functions ultimately contribute to the number of subordinates reporting directly to each supervisor. There is no unanimously acclaimed optimum ratio. Arguments pro and con surround the ideal *span of control,* the number of subordinates one man can adequately supervise.

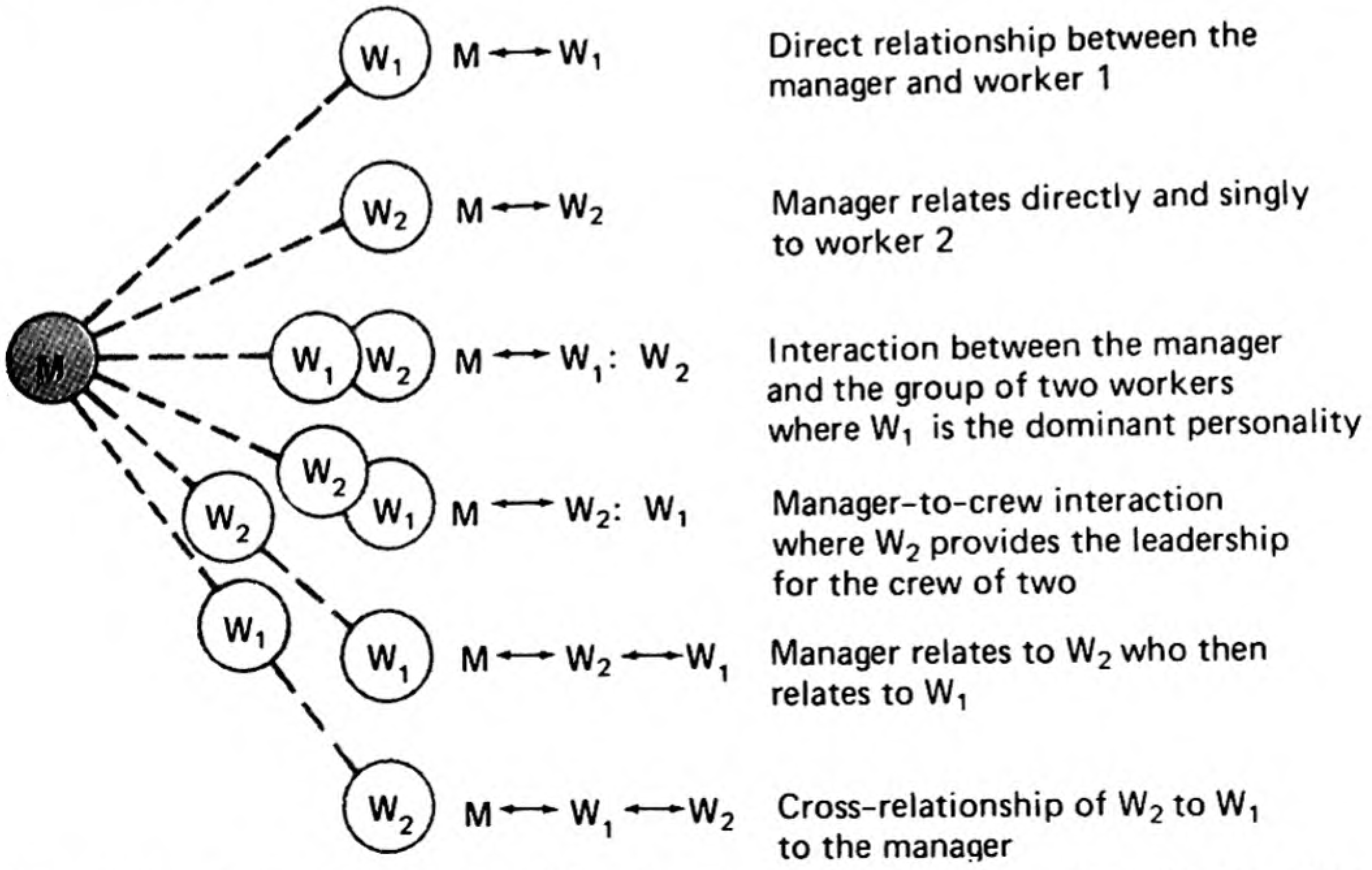

M
W1
M ↔ W1
Direct relationship between the manager and worker 1
W2
M ↔ W2
Manager relates directly and singly to worker 2
W1 W2
M ↔ W1: W2
Interaction between the manager and the group of two workers where W1 is the dominant personality
W2 W1
M ↔ W2: W1
Manager-to-crew interaction where W2 provides the leadership for the crew of two
W2 W1
M ↔ W2 ↔ W1
Manager relates to W2 who then relates to W1
W1 W2
M ↔ W1 ↔ W2
Cross-relationship of W2 to W1 to the manager

*Fig. 3-9. Potential relationships for a supervisor to subordinate ratio of 1:2.*

Advocates of a small span of control, fewer subordinates per supervisor, cite the geometric growth of potential person to person relationships that result from an arithmetic increase in subordinates. The smallest possible span of control is one manager (M) for one worker (W). Then only a single M ⟷ W relationship exists. Adding a second worker quickly inflates the number of potential relations to six as recorded in Figure 3-9. When the number of subordinates reaches three, the possible links rise to 18, and continue to increase, passing over 2,000,000 relationships for a crew of 18 with one supervisor.[4]

The existence of all sorts of relationships between a crew and its boss suggests that the span of control for a supervisor should be small. But how small is small? It is generally agreed that top executives should have fewer reporting subordinates than low-level managers, perhaps three to nine.[5] The reason for decreasing the span of control as responsibility increases is quite evident when the complex relationships that exist among high-level managers are compared to the relatively simple affiliations of a foreman with manual laborers.

The claim that a narrow span is beneficial because it fosters closer supervision is countered by contentions that it raises supervisory costs and may hurt motivation. It is assuredly true that for a given number of subordinates a smaller span of control necessitates more supervisors. If the organization consistently adheres to smaller spans, there will be more levels of management in the hierarchy, possibly hampering the communication flow that is a theoretical attribute of fewer management levels. In addition, more layers of bureaucracy could stifle initiative by making advancement steps seem too small and too many to the energetic newly hired manager.

Many more considerations affect the issue. In fact, the influencing factors vary so much in quantity and degree that unusual combinations can upset regular manager-to-worker ratios. Some of the more notable factors are

1. *Capabilites of the individual manager to deal with groups*—his personality and willingness to use assistance
2. *Characteristics of the group*—members' attitudes toward the job and each other, their experience and training
3. *Physical conditions on the job*—how standardized the processes are and how widely the workers are dispersed
4. *Nature of the work*—outside demands on the time of the manager and workers, degree of familiarity with the work, occurrence of unexpected interruptions, and amount of coordination needed

## PATTERNS OF ORGANIZATION

Upon the *foundations* described in the preceding section are built organizational structures of all shapes and sizes. The principles discussed are more guidelines than blueprints for designing an organization. The guidelines can allow many different patterns. Selecting the best pattern for a particular situation is like constructing a picture with colored tiles. The frame to be filled with tiles is akin to a company's directional policies. Different colors and shapes of tile correspond to different skills and capacities of people. The ceramic artist fits the pieces together within the framework to compose a balanced, coordinated picture that captures the overall effect he desires. So does the management artist.

### Triangular Pattern

The vast majority of organizations can be represented by a triangle. The broad base of the triangle characterizes workers directly associated with production—craftsmen building, field workers harvesting, salesmen selling, clerks transcribing, instructors teaching, delivery men distributing, etc. Although the occupations on the output line vary among industries, this collective category is the largest in the triangle. Successively smaller categories are comprised of people who coordinate resources to support the output line. These functions are shown in Figure 3-10.

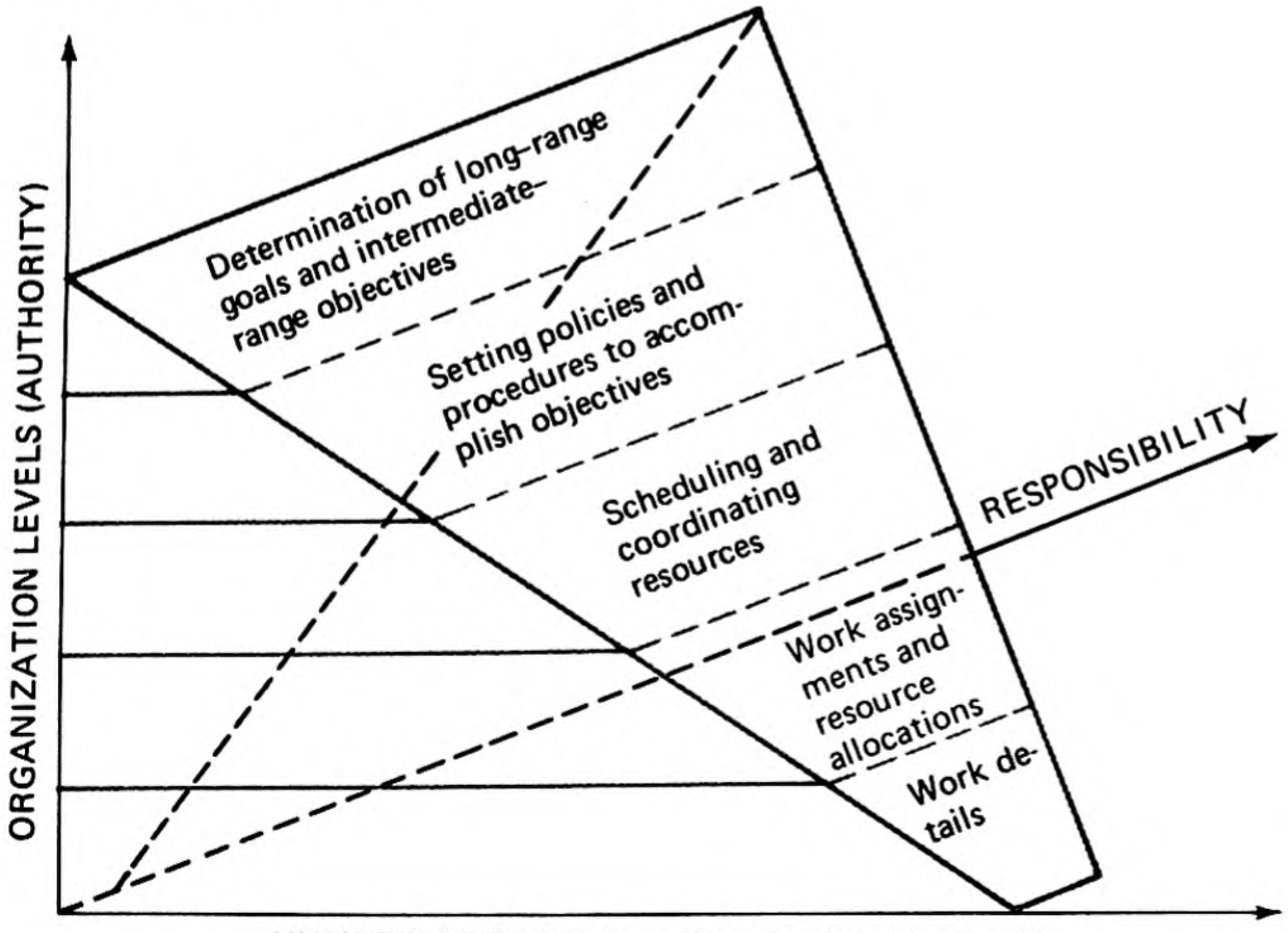
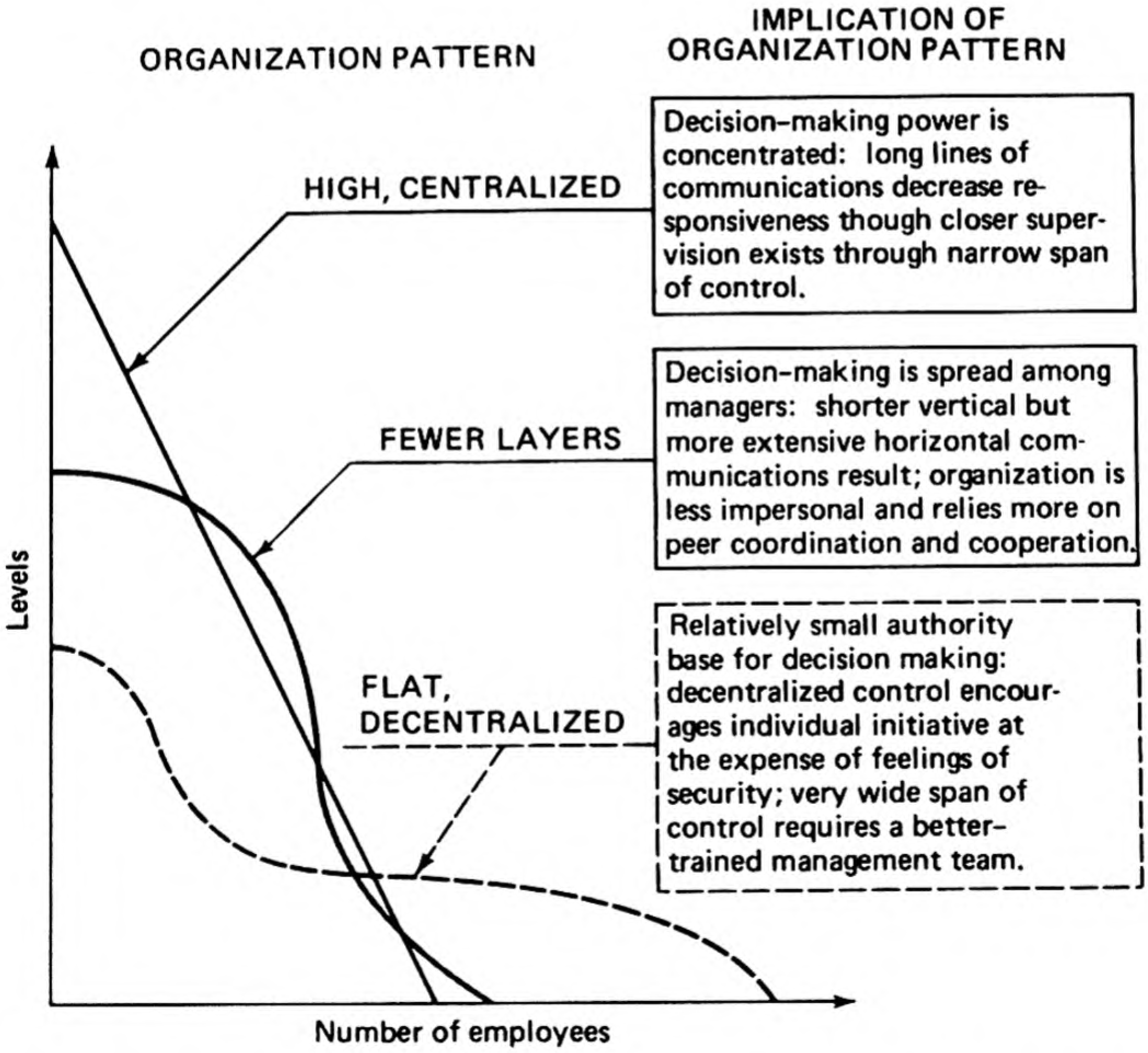

ORGANIZATION LEVELS (AUTHORITY)
NUMBER OF PEOPLE IN THE ORGANIZATION
RESPONSIBILITY
Determination of long-range goals and intermediate-range objectives
Setting policies and procedures to accomplish objectives
Scheduling and coordinating resources
Work assignments and resource allocations
Work details

*Fig. 3-10. Functions associated with the personnel profile of an organization. Factors such as wages, range of activity, and accountability vary inversely with the population.*

Another triangle, proportioned in reverse, can be derived when responsibility considerations are linked to organization levels. Then the triangle is large at the top. This condition, portrayed in Figure 3-10, partially explains why wages also increase for services performed at the higher levels. Some of the other characteristics that vary inversely with the population profile of most firms are

1. *Longer planning horizons*—factors affecting operations months or years in advance are considered.
2. *Greater freedom of action*—many companies set levels of spending for each level of management; for instance, a department manager would be allowed to make a single expenditure up to $1,000 without seeking the approval of his boss.
3. *Wider range of events to consider*—activity coordination includes the most significant events for all lower levels; this accumulated accountability is a source of take-home duties and frayed nerves popularly associated with managers of managers.



Decision-making power is concentrated: long lines of communications decrease responsiveness though closer supervision exists through narrow span of control.

Decision-making is spread among managers: shorter vertical but more extensive horizontal communications result; organization is less impersonal and relies more on peer coordination and cooperation.

Relatively small authority base for decision making: decentralized control encourages individual initiative at the expense of feelings of security; very wide span of control requires a better-trained management team.

*Fig. 3-11. Three triangular organization patterns with their implied influences on operational activities.*

The organizational triangle is both the cause and the result of the way management operates. Many studies have been made to observe the way an enterprise functions in relation to its organizational structure.[6] The research furnishes no assertive rules for structure design, but insights are offered on the behavioral effects associated with different designs. Three versions of a triangular organization with character implications are presented in Figure 3-11.

### Rectangular Pattern

Rectangular, matrix, product, or project management, whichever it is called, is a relatively new pattern of organization. Some say it was conceived by the Procter and Gamble Company in the 1930s, and others credit General Electric with a later introduction. Only in the last decade, however, has it received very much attention. Most of that attention was created by its application to weapons production.

Developments in weaponry of almost science-fiction design are characterized by huge expenditures, highly advanced technology, complex coordination problems, and an urgency for completion. A special form of organization emerged to cope with these large scale, diverse factors. The pattern that evolved was a two-dimensional matrix, one dimension being the different weapons under development and the other the regular functional line-staff components. As displayed in Figure 3-12, the rows of the matrix represent independent products or projects (weapon-systems code names) and the columns are the support units for the project (line departments).

Civilian counterparts to weapon programs are based on well-identified production or service projects such as a dam, section of a highway, educational unit, etc.

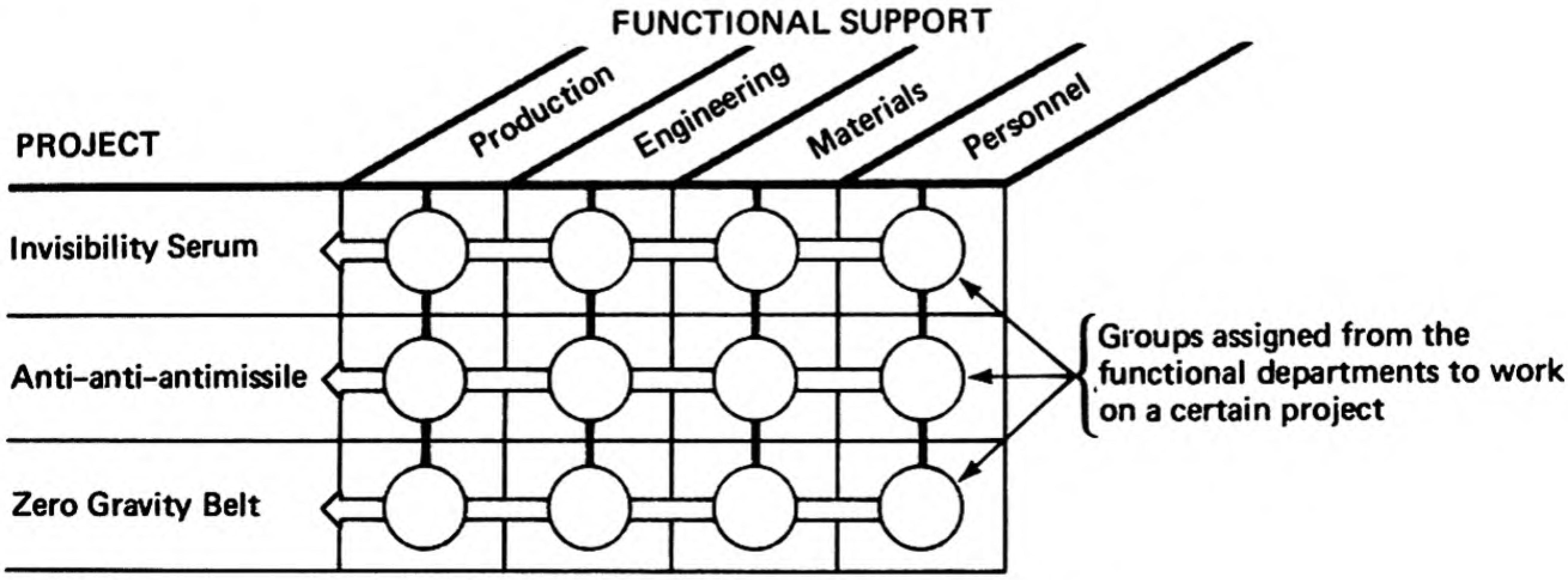

FUNCTIONAL SUPPORT
PROJECT
Production
Engineering
Materials
Personnel
Invisibility Serum
Anti-anti-antimissile
Zero Gravity Belt
Groups assigned from the functional departments to work on a certain project

*Fig. 3-12. Matrix organization for large-scale weapon projects.*

Sample applications to government service and product management are given below.

| | **State Police Dept.** | **Motor Vehicle Dept.** | **Highway Division** | **Public Utility Commission** |
|---|---|---|---|---|
| Traffic Safety Unit | XXXX | XXXX | XXXX | XXXX |
| Program B | XXXX | XXXX | XXXX | XXXX |

*X's represent participation from each department.*

| | **Manufacturing** | **Facilities** | **Financing** | **Personnel** | **Marketing** |
|---|---|---|---|---|---|
| Super Soap Manager | XXXX | XXXX | XXXX | XXXX | XXXX |
| Brand B Manager | XXXX | XXXX | XXXX | XXXX | XXXX |

*X's represent product personnel supplied from each area.*

The departure of rectangular patterns from triangular organization designs is more significant internally than can be made vivid in a chart. The most obvious difference is the premeditated denial of the one-boss decree. Under the two-dimensional arrangement each worker has dual responsibility, first to the *project* or *program* manager for duties related to producing a special product and second to a *line* manager on matters related to functional contributions to his normal departmental output. Criss-crossing lines of command invite close cooperation by opening direct communication channels between workers and staff as well as line members. However, crossing patterns of authority also contribute to confusion when work orders conflict. Whom do you believe?

The project manager is theoretically the boss of the bosses. He exerts authority across traditional department lines. Though he does not have exclusive "command" over functional line managers, he has final say for any reasonable alternative within the realm of his project. He spends much of his time coordinating detachments from the regular line departments to accomplish project missions. Since the project manager is accountable for all conditions affecting completion of his project, he exercises complete budgetary control. Power of the purse confirms and consolidates his sweeping authority.

### Patterns within Patterns

Outlines of organizations follow many patterns—triangles, rectangles, spirals, and combinations thereof. Some charts are emblazoned with all the names and titles from the big boss to the lowest helper. Some attempt to depict all the authorized contacts and reporting relationships between individuals, while others claim only to be a directory of functions. Regardless of its rollcall completeness, a chart is only an x-ray of a corporate body. It outlines the skeleton. It cannot display all the nerves, muscles, and blood vessels that keep the body healthy.

The boxes of the skeletal chart capture the main divisions of work and the superior-subordinate relationship of those who are expected to do the work. They imply degrees of responsibility and authority. They suggest which positions are line and which are staff. But the complete workings cannot be shown due to psychological differences in the individuals filling charted positions. Stronger individuals tend to make their positions more influential than others diagramed at the same management level. Even if true influence could be diagramed, the levels would be out of date as soon as the names in the boxes changed.

Within the formally proclaimed organizational structure is another organization. This other structure corresponds roughly to the nerves and blood vessels of the corporate body. It is a sensing and communication network, complex and very important. It augments the formal operating mechanisms through more personal work relationships and a maze of communication channels. Committees and the grapevine are standard components of the informal organization.

**COMMITTEES.** Everyone reading these words has probably been on a committee. And everyone has likely heard some insulting definitions of a committee—"a collection of the uninterested led by the uninspired to perform the unnecessary" or "a group of persons who keep minutes but throw away hours." In spite of the jokes, committees are a widely used, perhaps overused, arrangement to provide advice, pass information, seek consensus, or develop ideas. They are not noted for their proficiency in making tough decisions.

Composition of a committee should be tailored to the functions it is to perform. In Chapter 2, committees employed as idea generators were supposed to include people with different backgrounds and specialties. A more homogenous makeup is good for treating special problems relevant to a particular function or for indoctrination in a specific subject.

Committees may operate as line or staff auxiliaries, or both at once. Take the situation where a foreman recognizes that a safety problem exists for a certain operation, but he does not know the best way to relieve it. He could call a meeting of affected operators to seek their advice. They would likely meet several times if the solution was not immediately apparent. After preventive measures were decided upon and the implementing rules were framed, the committee would be disbanded. But during their period of activity, the committee members served the staff function of providing specialized knowledge and the line function of translating the advice into work rules. Further, since the operators who are to employ the work rules participated in formulating them, their compliance to those rules should be no problem.

A successful committee is a reflection of a competent leader or chairman. The setting he arranges and his conduct of the meetings strongly affects the committee's performance. He has to be patient but he needs to urge action. He cannot dictate but he has to give direction. He seeks cooperation and consensus but he cannot even ensure harmony.

There are occasions when the committee leader disagrees with the majority opinion. Since he is the one primarily accountable for the results of the committee's performance, he can go along with the majority and point out his reservations. He can carry the issue to higher authority for counsel, or he can exercise his right of final responsibility to reverse the majority recommendations. A null response to a committee action quickly discourages the members and diminishes the chance of future effective action. A reversal releases the committee members from responsibility for any errors arising from the final recommendation but still discourages future participation. A good committee manager is a diplomat with a conscience, an administrator with charisma.

Too much reliance on committees can harm an organization. Each time a committee is about to be established the pros and cons should be weighed. Committees are traditionally slow acting and tend to outlive their purpose, but during their period of usefulness they can deliver advice supported by broad experience. New managers can receive training and exposure from committee participation, but they can also create poor impressions or get involved in conflicts that will later haunt them. Regularly scheduled meetings can save time by allowing participants to anticipate and prepare for concentrated study; unprepared-for meetings may waste time for those not really concerned with the scheduled topics, and rambling discussions can squander time for everyone.

In deciding when a committee should be used to supplement the established organization pattern, the first point to ponder is whether one person or a group of persons can do the job better. There are fewer delays with one person, but there is safety in numbers.

**THE GRAPEVINE.** Only the very rare organization lacks a grapevine, a casual but penetrating communication network. Some critics call it a rumor circuit or the gossip line. Nearly everyone has occasion to marvel at its speed. Almost no one acclaims its accuracy.

People like to know what is going on, what to expect. When something unusual occurs, or is thought to have occurred, they are eager to hear about it. It also seems to be human nature that each listener feels free to edit the message before passing it along. These embellishments may add perspective to the message, but they seldom increase its accuracy.

Since the grapevine is going to operate with or without recognition by the establishment, managers may as well admit its inevitability and even make use of it when appropriate.

Just as each enterprise has its own formal organization pattern, also it has its own grapevine pattern. Membership in the grapevine network varies with time and the topic being transmitted. However, some groups and individuals are more stable members than others. These active transmitters usually enjoy a reputation

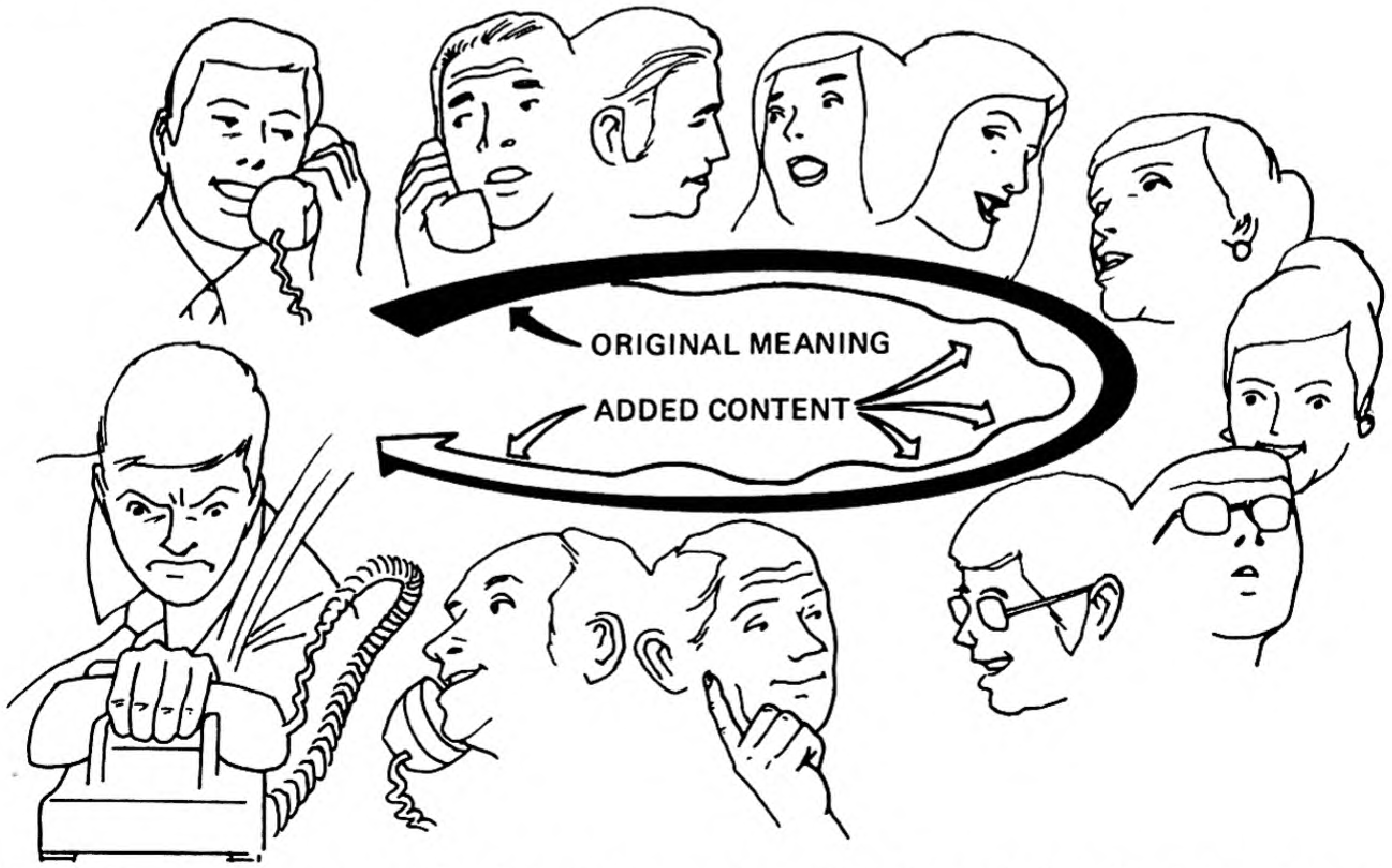


*Fig. 3-13. A message passing into the grapevine whirls through the circuit to return to its source almost unrecognizable due to the distortions and embellishments it accumulates along the way.*

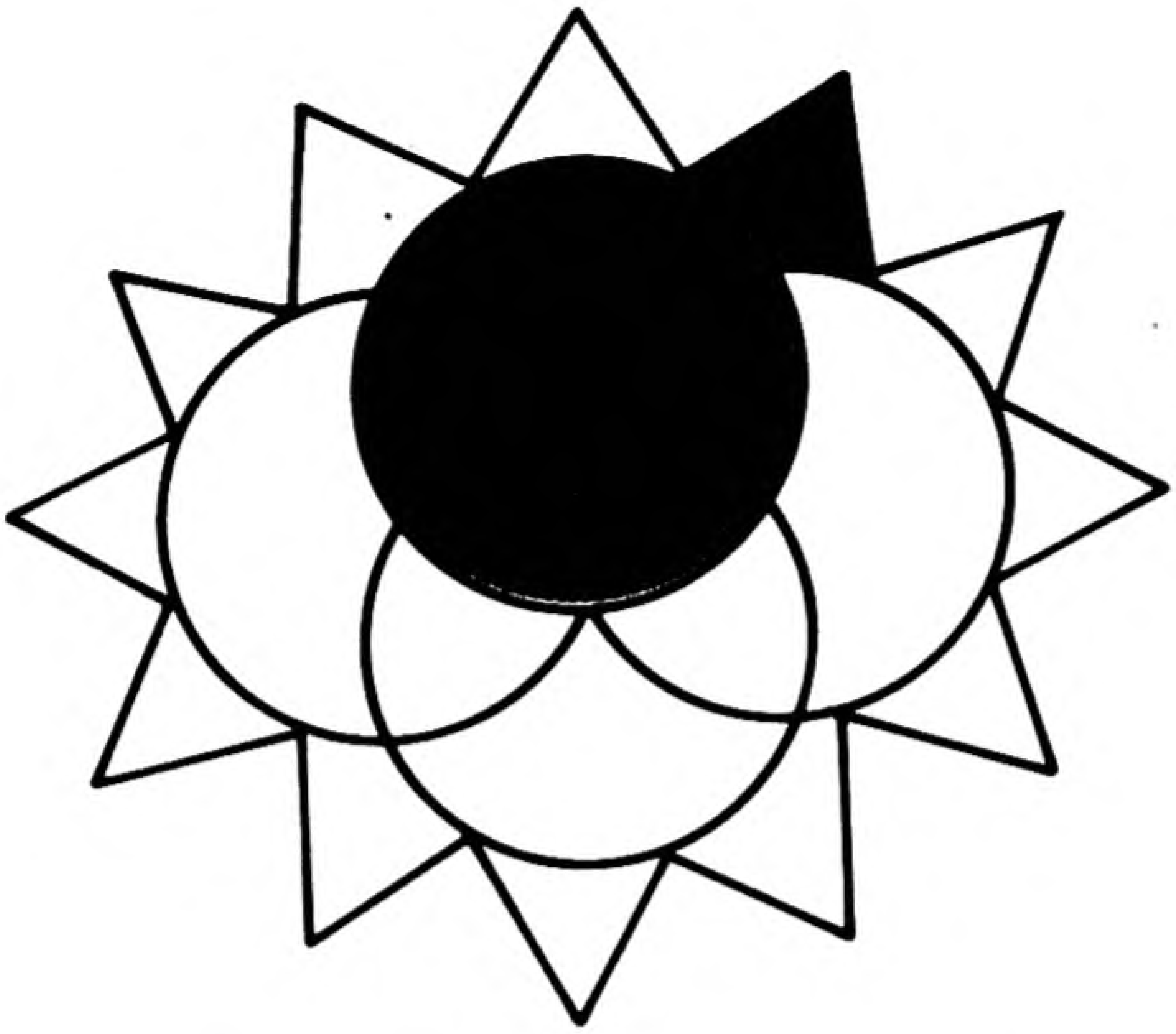
for having the "hot news" or a "pipeline to the top." A manager who is aware of the more energetic newsmongers knows where to seek or plant reports. But he cannot be sure of results. The spontaneous nature of a grapevine reduces reliability. Sometimes only the good part of the news is passed along to protect the listener's feelings, or only the bad part is told to satisfy some motive of the teller. Always there is the chance for misinterpretation owing to the choice of words used in transmission.

Assuming a manager has access to a contact point in the grapevine, he may be able to get early warning of brewing troubles. Along with clues as to what is happening elsewhere in the organization, he might learn how his own actions are received. Malicious rumors can be countered by official communiqués if the slander is heard in time. Feeding information directly to the grapevine may be the best way to treat situations when the message will be more effective by masking the source, as in an occasion where someone's reputation would suffer from an official pronouncement. Such insertions deserve delicate handling because grapevines are notoriously irresponsible media, as suggested in Figure 3-13.

## REFERENCES

1. Norman Vincent Peale, "You Can Stop Being a Procrastinator," *Reader's Digest,* vol. 100, no. 597, January 1972.
2. Charles R. Walker and Robert H. Guest, *The Man on the Assembly Line,* Harvard University Press, Cambridge, Mass., 1952.
3. A widely quoted study at IBM is described in Charles R. Walker's "The Problem of the Repetitive Job," *Harvard Business Review,* May 1950.
4. Harold Koontz and Cyril O'Donnell, *Principles of Management,* 4th ed., McGraw-Hill Book Company, New York, 1968.
5. Ralph C. Davis, *Fundamentals of Top Management,* Harper & Brothers, New York, 1951.
6. Joan Woodward, *Industrial Organization: Theory and Practice,* Oxford University Press, London, 1965.

# Chapter 4



# Budgeting

**KEY SUBJECTS**

*Basic budgeting entails assigning monetary values to plans, balancing receipts and disbursements for effective use of capital, and comparing actual to planned cash flow.* Financial tabulations that assist the budgeting process include balance sheets, profit and loss statements, and budget sheets. Budget figures act as incentives for achievement as well as warnings about the effects of underachievement.

*Budgeting in a large organization embraces many steps and many people.* Objectives are aimed high enough to avoid complacency, yet reasonable enough to prevent frustration. Estimates of expenditures and income may pass from the foreman level up to higher management and back to gain everyone's participation and conformity. More detailed budgets provide closer control at the expense of higher preparation and administration costs. Flexibility is attained by using variable budgets and periodic budget reviews.

*A breakeven chart displays the relationship of costs and revenues as functions of operating volume.* Different chart formats are used to emphasize aspects of interest. Several simplifying assumptions are incorporated in typical breakeven charts to make the data display more compact and easily understood. Numerical expressions of cost and volume assist the analysis of data.

*Capital is budgeted to ensure money is available when needed and investment opportunities are carefully evaluated.* Many comparisons are immediate in nature because necessary facts are known, risk is insignificant, and the time span involved is short. Investments with cash flows stretching beyond one year should be evaluated in terms of the time value of money.

*Three comparison methods for ranking competing proposals for capital investment are the payback period, average annual return, and present worth.* The payback method shows how quickly an investment will pay for itself. The difference between the yearly operating advantage earned by an investment and the average investment cost gives the average annual return. The present worth is the sum of all receipts and disbursements associated with an investment discounted to the present time. Discounted cash flow diagrams assist the calculations.

## THE MONEY-GO-ROUND

"The name of the game is business and the score is kept with money" is a catchy old saying that contains a lot of truth. Perhaps business is too serious to be called a game and more is involved in the score than money, but it is hard to name a better yardstick. Money is the essence of all industrial enterprise. In a more obscure way it nourishes all nonprofit government institutions too.

Money management is another aspect of *organizing* treated in Chapter 3. Here attention is given to the flow of capital instead of information, to the structure of

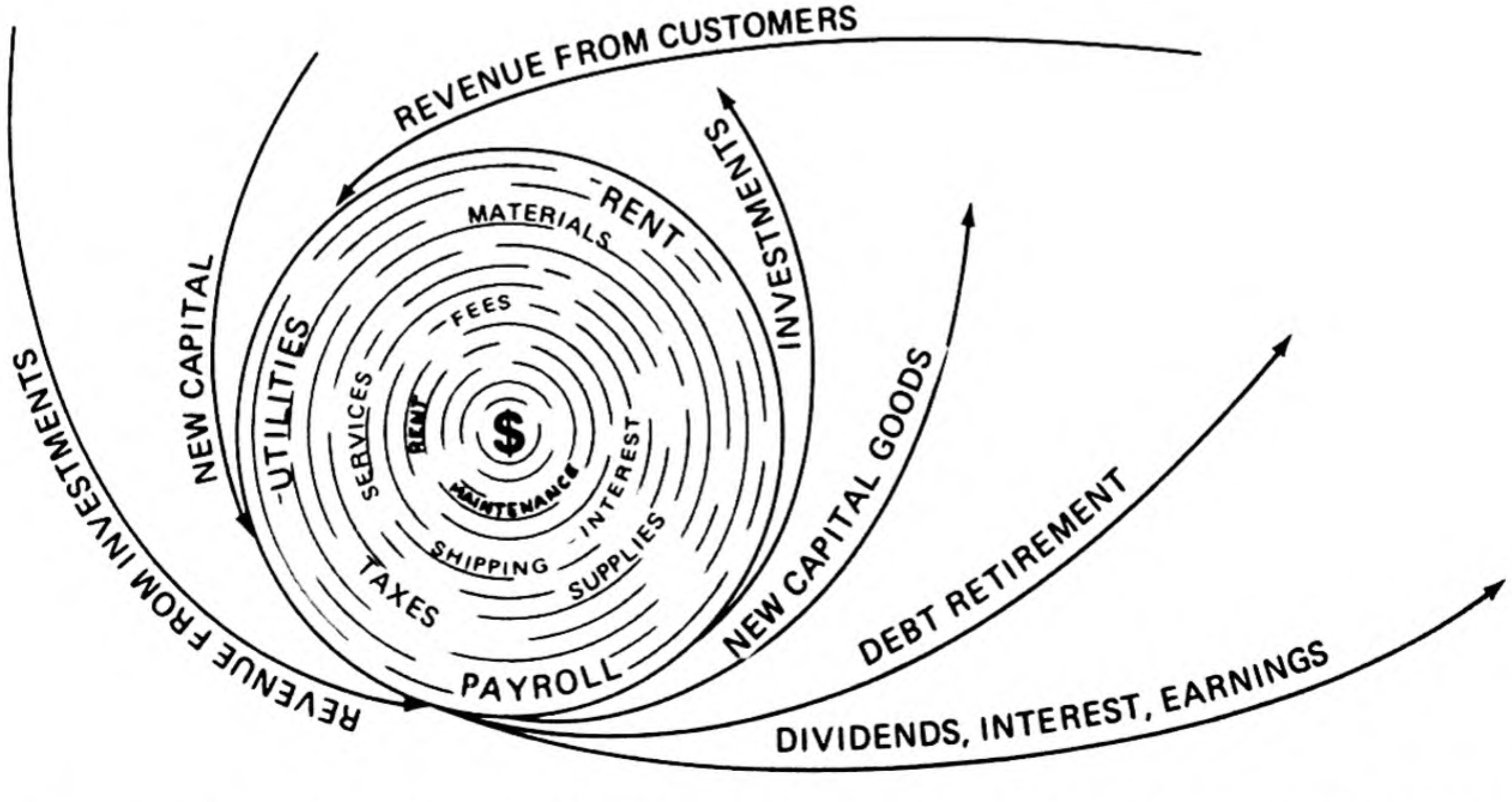

REVENUE FROM CUSTOMERS
INVESTMENTS
NEW CAPITAL
REVENUE FROM INVESTMENTS
RENT
MATERIALS
FEES
UTILITIES
SERVICES
RENT
$
MAINTENANCE
INTEREST
SHIPPING
SUPPLIES
TAXES
PAYROLL
NEW CAPITAL GOODS
DEBT RETIREMENT
DIVIDENDS, INTEREST, EARNINGS

*Fig. 4-1. Cash-flow pinwheel indicating major sources of income and disbursements of money.*

accounts instead of personnel positions. Still, the flow channels and the structures have to be well designed. The design starts with budgeting. Some of the cash-flow considerations important to budgeting are depicted in the pinwheel of Figure 4-1.

Some degree of financial budgeting is necessary for anyone who consistently exchanges money for goods or services, and that includes almost everyone. Basic budgeting is a three-step process: (1) assigning monetary values to plans, (2) balancing planned receipts and disbursements for most effective use of capital, and (3) comparing actual to planned cash flow. In the following sections we will not go into the details of accounting and internal financial operations; we will attempt instead to see how budgeting aids and is aided by other management practices.

## BASIC BUDGETING

Education in budgeting starts very early in life. Although a child with his allowance may not be aware of it, he is engaged in rudimentary budgeting when he converts his wants into costs, assigns a portion of his money to satisfy his most urgent craving, and wonders where his money went. A few years later as a college student, newlywed, or employee, budgeting gets more binding. The routine is the same, only the stakes are higher.

To reveal some implications of the budgeting function, we will consider the financial aspects of initiating a new business. By limiting the scope of the venture we can examine conditions more encompassing than those of a household budget, but less intricate than the interwoven transactions of a big corporation. The important thing to observe is how budgeting contributes to analysis and coordination of operations.

To supplement his salary from teaching, Mike Miller moonlighted as a sales representative for a picture-postcard distributing firm. Within his assigned territory he called on restaurants, service stations, and other tourist stops to replenish postcard racks and service the accounts. As he traveled, he speculated that his distribution route could be more effective if other product lines could be added to make better use of his travel time.

Miller got a chance to convert his speculations to reality when the owner of the distributorship decided to sell out and retire. The owner wanted $41,000 for his inventory of cards, a small warehouse, and ongoing business. Miller met the asking price with $11,000 from his savings, a $10,000 bank note, and a loan from the former owner secured by a mortgage on the warehouse. He still retained enough savings for his own living expenses for one year plus $10,000 to use for working capital. Thinking big, he named his new company *Universal Supply Services*. The beginning balance sheet for USS appeared as shown in Table 4-1. A balance sheet reveals assets (what the company owns), liabilities (what it owes), and net worth (difference between the value of assets and liabilities).

TABLE 4-1. BALANCE SHEET FOR UNIVERSAL SUPPLY SERVICES

**USS—FOUNDING CONDITION**

**Balance Sheet as of January 1**

| | | | |
|---|---|---|---|
| Cash | $10,000 | Accounts Payable | $ 1,900 |
| Accounts Receivable | 2,400 | Accrued Taxes, etc. | 200 |
| Inventory | 13,100 | Current Liabilities | 2,100 |
| Current Assets | 25,500 | Note from Bank | 10,000 |
| | | Loan from Owner | 20,000 |
| | | Total Liabilities | 32,100 |
| Warehouse and Equipment | 27,600 | Equity of Mike Miller | 21,000 |
| Total Assets | $53,100 | Total Liabilities and Equity | $53,100 |

Miller knew exactly what he wanted to do with USS. He was not worried about competition. By maintaining good service for his clients he could expect postcard sales to be about $80,000. From this amount he would net $40,000 and his expenses would be between $29,000 and $32,000 if he did most of the route work. The resulting profit would provide a reasonable return for his effort, but he thought he could do better by expanding. As long as he had to make the calls anyway, why not add a second line to go along with the postcards? He added novelty salt and pepper sets.

Before buying the distributorship he had secured a franchise for the S&P sets. They came with an attractive display case, were reasonably priced, had been well received in other parts of the country, and had a favorable wholesale cost. Of course, there was some risk in adding the S&P line owing to the initial investment in inventory and display cases without really knowing how sales would go, but potential profits made the risk seem worthwhile.

Using conservative but realistic estimates, Miller developed a forecasted profit and loss statement for the year. The statement as given in Table 4-2 revealed the limited immediate gain to be expected from introducing the S&P line; to get the line started Miller felt he would have to do most of the contact work with the outlets. Consequently he had to hire extra route men to take the load of postcard distribution. It also became apparent that he would have to maintain close control over his inventory in order to adjust it downward quickly if sales failed to reach expected levels. He was confident, however, that his net profit would at least equal that from postcard sales alone and that he could expect larger future profits once the S&P line was installed.

As Miller studied the profit and loss picture, the narrow profit margin convinced him to detail further his operating plans for the year. He was worried about his cash flow. Past experience suggested that postcard sales would gradually increase to a peak during the summer tourist season and then recede gradually. From the current January date until late spring, he could not expect much income. During the same period he would have to build up his inventory of salt and pepper sets and distribute S&P displays as widely as possible. His cash position would be tight.

TABLE 4-2. ANTICIPATED PROFIT AND LOSS STATEMENT FOR THE FIRST YEAR OF OPERATION OF UNIVERSAL SUPPLY SERVICES. THE INCOME AND EXPENSE CATEGORIES SUMMARIZE THE EXPECTED EFFECTS OF OPERATIONS DURING THE 1-YEAR PERIOD ANALYZED.

**USS—TENTATIVE ANNUAL BUDGET**

**Anticipated Profit and Loss Statement**

| | | |
|---|---:|---:|
| Net Sales: Postcards | $80,000 | |
| S&P sets (20,000 @ $1.50) | 30,000 | |
| Total Net Sales | | $110,000 |
| Cost of Goods Sold: Postcards | 40,000 | |
| S&P sets (20,000 @ $0.60) | 13,200 | |
| Total Cost of Goods Sold | | 53,200 |
| Gross Profit on Sales | | 56,800 |
| Expenses | | |
| Route Men Salaries (2 part time) | 14,000 | |
| Travel Expense | 12,000 | |
| Office Salaries (contracted) | 7,000 | |
| Office Expense (supplies, utilities, etc.) | 2,100 | |
| Warehouse Expense (insurance, taxes, etc.) | 4,000 | |
| Loan Repayments (bank and owner) | 5,200 | |
| Total Expenses | | 44,300 |
| Net Operating Profit | | 12,500 |
| Income Tax | | 2,500 |
| Net Profit | | $ 10,000 |

A monthly budget was constructed, Table 4-3. As Miller juggled the costs of his planned activities, he had to compromise his more ambitious goals to stay within the limits of his working capital. He allowed his inventory of postcards to decrease almost 20 percent by April in order to push salt and pepper sets. By June he anticipated having all his outlets fully stocked for the main selling season. If events went as planned, his cash level would reach a minimum in July and then increase rapidly. If sales did not meet expectations in July, he could cancel orders for inventory and reduce his summer help. Budgeted values act as incentives for achievement as well as warnings about the effects of underachievement.

With the operating plan laid out for the year, Miller has satisfied the first two steps of budgeting. The third step remains, comparing actual to planned cash flow. Accounts for operations must be kept current for the budgeting comparisons to be effective. Variations need not occasion any panic, but they should serve as a reason to look over current conditions in terms of previous estimates to see what corrective measures, if any, are appropriate. The way each category is sensitive to level changes in several other categories underlines the need for cooperation and coordination between departments. That activities throughout an enterprise are inevitably interdependent is confirmed even by the sparse entries of the USS budget. Just one runaway entry can break the budget, drawing off funds from all activities indiscriminately. Budget checks can discover the break before it gets too serious.

## BIGGER BUDGETS

The purpose of budgeting is the same regardless of the budget's size. It is a game plan. The bigger the game, the more elaborate the plan. But the score is still kept with money.

Bigger businesses are divided along one of the lines suggested in the last chapter. Big budgets usually begin at the department level. Foremen and supervisors are asked to predict expenditures or income. These predictions are reviewed at the next higher level, then passed along for more reviewing at still higher levels. Revisions are passed up and down the hierarchy in the search for conformity and harmony.

Wide participation in the budgeting process, especially at the lower levels, makes more people aware of how their contributions coordinate with the total program, but consistency is difficult to obtain. For instance, a manufacturing superintendent bases his cost estimates on forecasts from the sales department and information from other departments such as purchasing, personnel, and research and

TABLE 4-3. MONTHLY BUDGET FOR CASH RECEIPTS AND DISBURSEMENTS OF UNIVERSAL SUPPLY SERVICES.*

| USS—MONTHLY BUDGET | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sales: Postcards | $5,000 | $4,000 | $5,000 | $5,000 | $7,000 | $8,000 | $9,000 | $12,000 | $10,000 | $6,000 | $4,000 | $5,000 |
| S&P Sets | | 500 | 1,000 | 1,500 | 2,000 | 3,000 | 4,000 | 5,500 | 4,500 | 2,000 | 2,000 | 4,000 |
| Cash Received | 5,000 | 4,500 | 6,000 | 6,500 | 9,000 | 11,000 | 13,000 | 17,500 | 14,500 | 8,000 | 6,000 | 9,000 |
| Disbursements: | | | | | | | | | | | | |
| Postcards | 1,000 | | 2,000 | 4,000 | 6,000 | 12,000 | 6,000 | 4,000 | 2,000 | 2,000 | | 1,000 |
| S&P Sets | 3,000 | 1,000 | 1,000 | 500 | 500 | 1,000 | 2,000 | 1,000 | 1,000 | 1,000 | 1,000 | 200 |
| Route Men Salaries | 600 | 600 | 600 | 600 | 1,400 | 2,100 | 2,100 | 2,100 | 1,950 | 650 | 650 | 650 |
| Travel Expense | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,300 | 1,300 | 1,300 | 1,100 | 600 | 600 | 800 |
| Office Salaries | 450 | 450 | 450 | 450 | 450 | 700 | 700 | 700 | 700 | 450 | 450 | 1,050 |
| Office Expense | 100 | 100 | 100 | 150 | 150 | 200 | 200 | 200 | 200 | 200 | 200 | 300 |
| Warehouse Expense | 180 | 180 | 180 | 220 | 220 | 280 | 640 | 340 | 280 | 220 | 1,040 | 220 |
| Loan Repayment | | | | | | | 1,700 | | | | | 3,500 |
| Cash Disbursements | 6,330 | 3,330 | 5,330 | 6,920 | 9,720 | 17,580 | 14,640 | 9,640 | 7,230 | 5,120 | 3,940 | 7,720 |
| Gain (or Loss) from Operation | (1,330) | 1,170 | 670 | (420) | (720) | (6,580) | (1,640) | 7,860 | 7,270 | 2,880 | 2,060 | 1,280 |
| Cash Balance ($10,000) | 8,670 | 9,840 | 10,510 | 10,090 | 9,370 | 2,790 | 1,150 | 9,010 | 16,280 | 19,160 | 21,220 | 22,500 |

*Since working capital is limited to $10,000, salary and postcard inventory expenses are restricted in the first quarter of the year to free funds both to build up a stock of S&P sets and to cover costs of establishing the S&P line. The cash balance reaches a minimum in July when additional summer help and a full inventory of stock are necessary to meet the seasonal sales demand. Receipts are expected to exceed disbursements during the last 5 months, producing before-tax income of $12,500 ($22,500 − $10,000) for the year.

development. At the same time, the sales department relies on estimates from manufacturing and other departments for input to their sales forecast. This circular dependence gets unwieldy unless someone superimposes a given set of conditions for all the subsidiary units to use in preparing their budget proposals. This master pattern should set goals high enough to avoid complacency, yet reasonable enough to prevent frustration from objectives believed to be unattainable.

The level of detail in a budget is determined by the usefulness of a finer breakdown in relation to the cost of its preparation and administration. The path of budget breakdowns generally proceeds from annual figures to monthly values and then from department quotas to quotas for categories such as materials and labor, and possibly to specific uses for materials and labor. Fine detailing could make a budget impossibly restrictive if provisions are not provided for flexibility. Most companies provide means to review the budgets periodically, say monthly, in anticipation of revisions needed to accommodate changing activity levels.

Alterations for budgeted values are made possible by use of variable budgets and standard costs. A *variable budget* is constructed to show in advance how certain costs vary with a change in volume of work. Costs are tabulated for different work levels and corrected to current conditions. *Standard costs* are developed through analysis of previously experienced expenditures to set a cost *per unit* for material, labor, overhead, or other expenses. The relationship of different types of costs to the use of facilities is explored as part of a breakeven analysis in the next section.

## BREAKEVEN ANALYSIS

Many of the expenses in a budget are easy to forecast because they change very little from year to year and are almost independent of the organization's level of activity. Such indirect expenses are called *fixed costs.* They are usually incurred as preparation for producing a product or providing a service. For example, before a carpenter can start building, he needs some tools. The purchase of a hammer and saw would be tallied as a fixed cost because it is the same outlay whether the tools are used on one or several buildings. Other costs in the same category include rent, insurance, property taxes, depreciation, advertising, and executive salaries.

Costs which are generally proportional to output are called direct or *variable costs.* These are the costs that have the flexibility to be modified when budget revisions are called for. Some of them are rather easy to estimate because the time and material needed for a unit of output are well known. A carpenter could give a very close estimate of how many nails would be required for a second identical building after he has built the first one. Similarly, the time he spends constructing the building is a direct cost. Other variable costs, some not so directly attributable to each unit of output, include maintenance, raw materials, purchased components, direct supplies, packaging, spoilage, direct supervision, and sales commissions.

### Breakeven Charts

The interaction between costs, revenue, and levels of output is conveniently visualized on breakeven charts. The breakeven-chart formula was developed by the industrial engineer Walter Rautenstrauch.[1] The essential pattern of a breakeven portrait of operations is shown in Figure 4-2. The vertical axis of the chart is scaled in dollars, representing revenues and costs. Across the horizontal axis is a scale of operational activity, possibly in units of output, volume of business, or percent of total capacity. Entries in the chart depict receipts or disbursements as a function of operating volume.

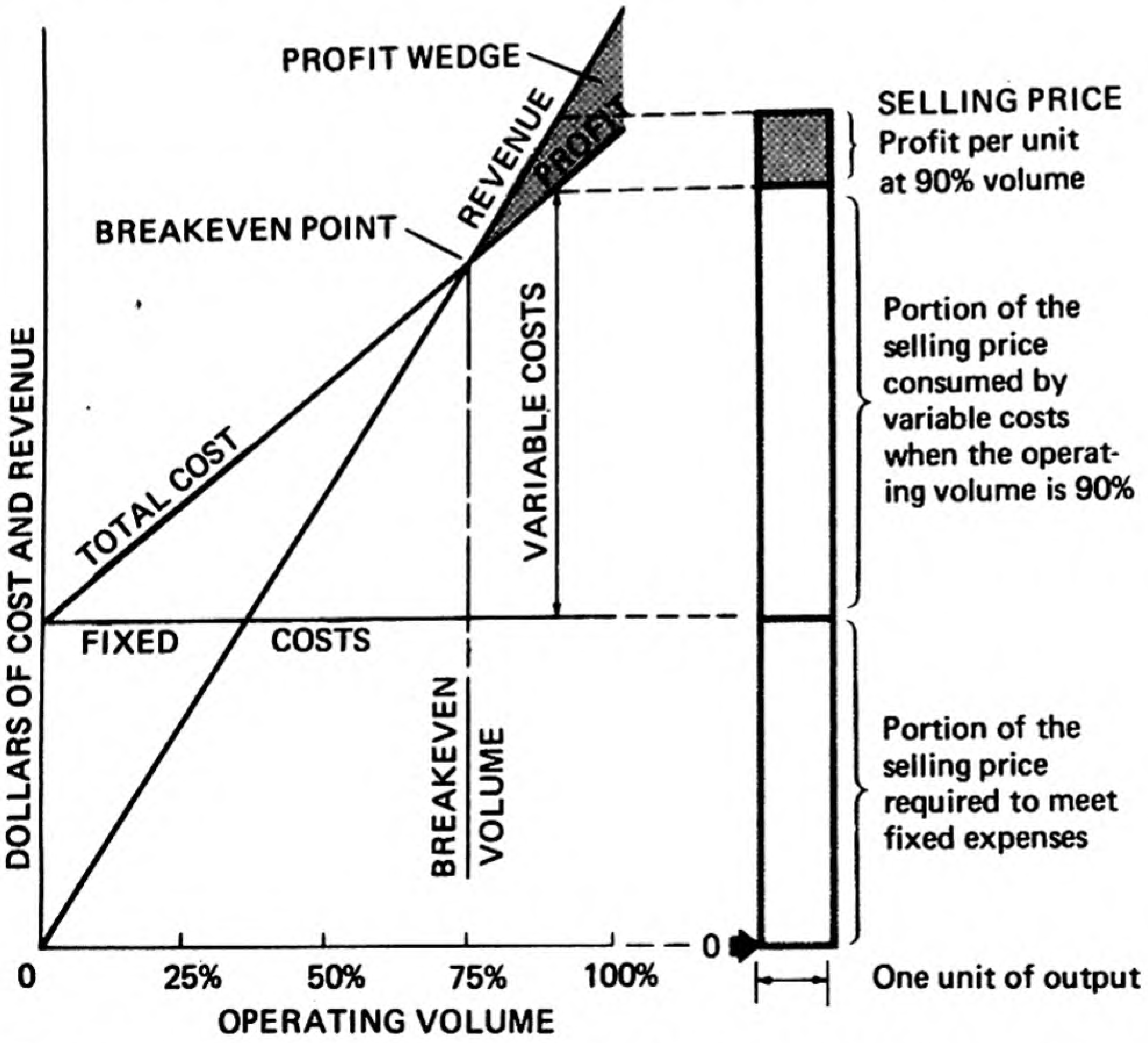


*Fig. 4-2. Pattern of a breakeven chart. The proportion of cost and profit for one unit depends on the total number of units made and sold during a given time period. If the total number is less than the breakeven volume, the selling price is completely consumed by costs.*

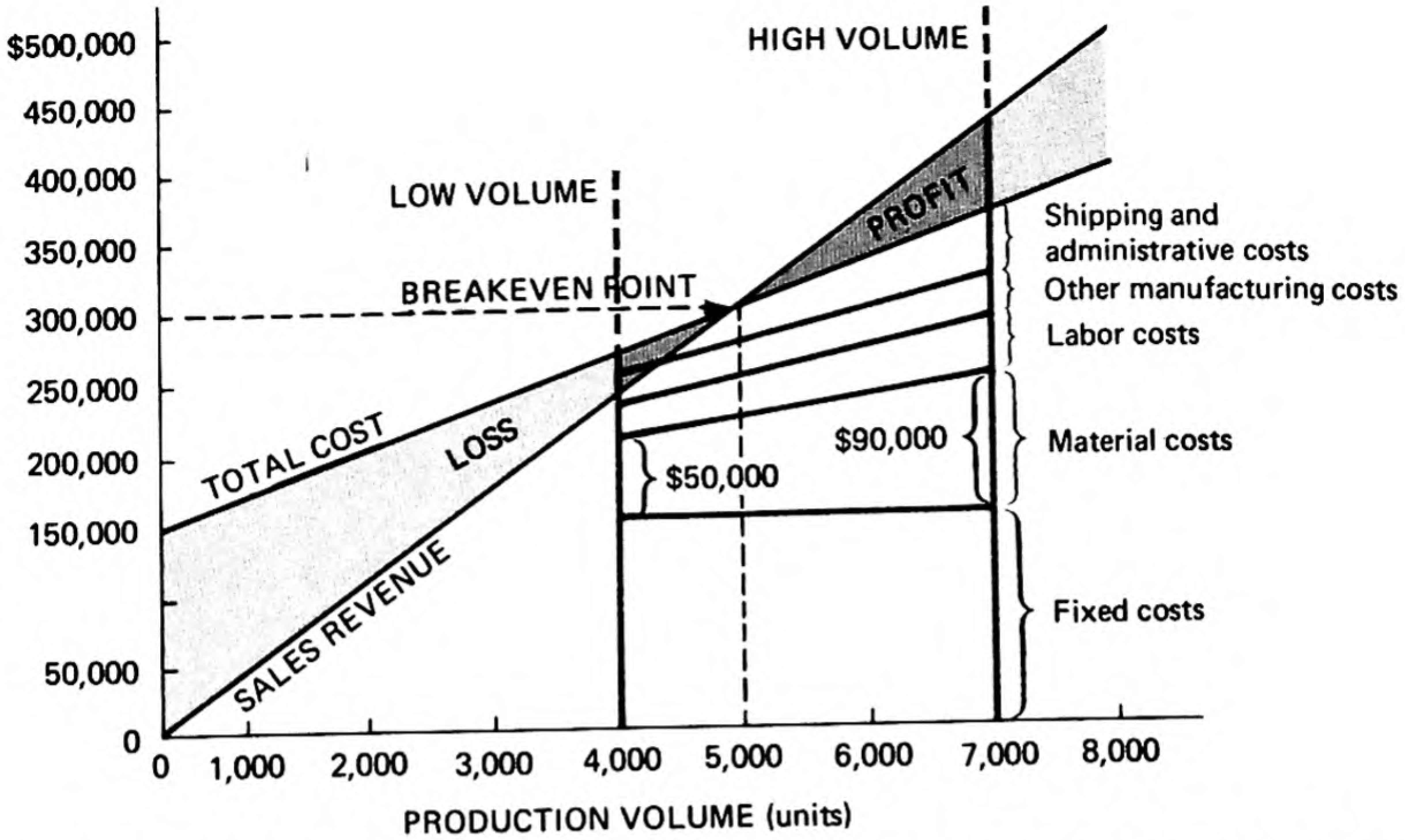


*Fig. 4-3. A breakeven chart partitioned to display the variation of costs within the region of expected production volume.*

The center of interest in the chart is the *breakeven point*, the intersection of the total cost and revenue lines that defines the operating volume required just to meet expenses. The area between the two lines beyond the breakeven point is the *profit wedge*. In addition to knowing the position of the breakeven point, it is important to recognize the shape of the profit wedge. A rapidly opening wedge, as opposed to a narrow taper, indicates greater profit on each additional unit made and sold, once the breakeven volume is attained. However, the same condition causes greater losses when volume fails to reach a breakeven position. The opposing wedges thus represent graphically the frequently encountered situation where the chance for greater gain is accompanied by a corresponding risk of larger loss.

Two assumptions embodied in typical breakeven charts are worthy of attention. The first is to recognize that the information in the chart is applicable only over a given time span, usually one year. From year to year, fixed and variable costs will change as a result of product redesign, addition of new processes or machines, or different pricing and marketing policies. The presumption that costs and revenues can be represented by straight lines is the second assumption. Actual operating conditions often exhibit nonlinear relationships for cost, revenue, or both. For instance, on the revenue curve a point may be reached where the market for an item is saturated and prices must be lowered to continue to sell more. Equivalently, the variable costs of reaching or exceeding a theoretical 100 percent capacity are often boosted above the normal linear scale by overtime payments and inefficiencies owed to overuse of the plant.

But an assumption of linearity is not a major concession. For most practical purposes a straight line is an adequate description of cost relationships. Many costs *do* increase linearly as volume increases, and even those that do not are closely approximated by a chord between points in the narrow area of concern for typical budgeting.

The use of a breakeven chart as a budgeting tool is implied by Figure 4-3. Because of uncertainty about demand for the coming year, operating budgets are sometimes developed for two or more levels of volume. The chart format shown emphasizes costs in the region of probable operation. Only the expense categories that vary with output level in the selected region are detailed. In actual practice, the cost categories would be broken down into finer divisions, such as different types of materials, to indicate the charges most sensitive to revisions in production volume.

Without having full information about the enterprise represented in Figure 4-3, several inferences about its operations can be surmised from the given data. The lack of advertising and the apparent confidence that sales revenue will not vary suggests that the market for the product is quite stable. Fixed charges are a relatively small proportion of total costs, indicating considerable flexibility is possible when cost revision measures are required. Since the expected operating range includes a production volume that could lead to a loss for the period, an early alert is needed for cost categories that would most easily aggravate the loss; material procurement is an obvious candidate because there is a $40,000 differential between the low- and high-output predictions.

The clarifying potential of breakeven charts is useful in other aspects of budgeting. As a presentation device, a breakeven chart can display a summary of all revenues and costs over a wide range of volumes for management explanations and discussions. It can assist short-range planning by portraying the economic effects from following different alternatives such as adding or deleting a product, purchase of a new machine that increases fixed costs but lowers variable costs, and the impact of proposed cost reductions to improve profitability. The simplifying assumptions of a traditional breakeven format detract somewhat from the reality of the visualization, but the chart provides a readily understood, compact, and meaningful digest to assist budgeting decisions.

### Breakeven Graphs

The concept of a breakeven point is applicable to selecting a preferred mode of operation. A graph of a single operation employs the same scales for the axes as those of a breakeven chart for complete operating conditions. The

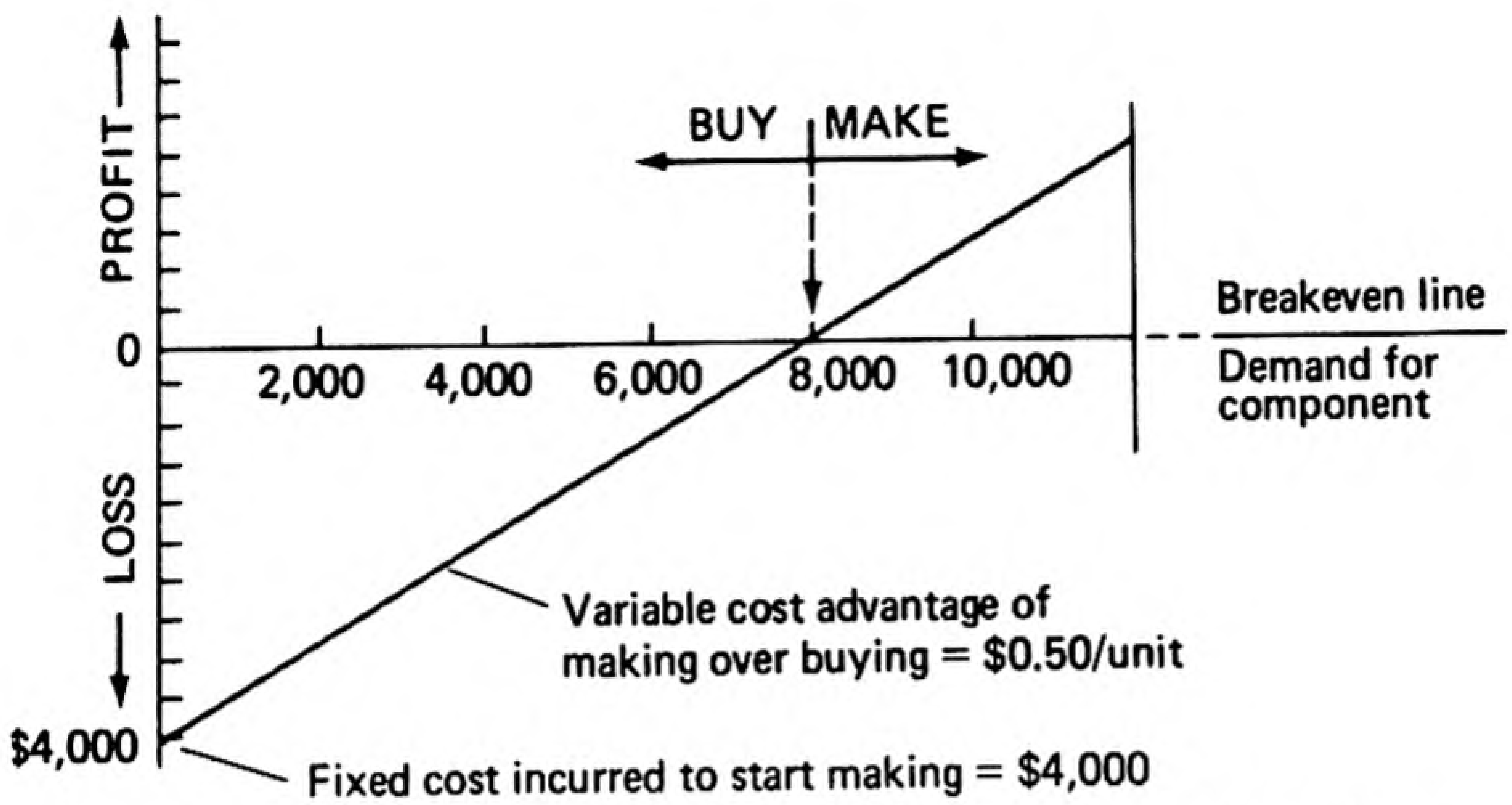


*Fig. 4-4. Breakeven graph that compares the cost of buying a component with the cost of manufacturing it. Assuming equivalent service and quality from both alternatives, the component should be made if total demand is expected to exceed 8,000 units.*

difference is in the orientation. A horizontal breakeven line splits the vertical dollar scale to produce a "loss wedge" on the left and a profit wedge on the right. The diagonal line responsible for the wedges represents the characteristic of the operation being analyzed.

Figure 4-4 is a graph of a "make or buy" situation. In a number of businesses many manufacturing operations can be conducted by the company making the finished product, or they can be done by an independent subcontractor. Similarly, components of the finished product can be manufactured internally or be purchased from outside suppliers. In either case, manufacturing involves certain fixed charges plus variable costs per unit, while buying the part or service involves only a direct cost for each unit. The variable cost from internal manufacturing will obviously have to be less than the purchase price or there would be no question of choice.

As recorded in the breakeven graph of Figure 4-4, the fixed cost of providing facilities to produce the component is $4,000 and the variable cost of manufacturing is $0.50 less than the purchase price of the identical component. Under these conditions, the breakeven point between the two alternatives is 8,000 units. If the demand for the component is expected to continue until more than 8,000 units have been used, the company should manufacture it.

The straightforward appearance of the graph might conceal some related considerations. The linear cost-comparison line implies a constant advantage from manufacturing the component during the entire period it is required. Since the demand rate is not given, the time span for expected use of the component is not known. Longer time spans place the assumption of a constant cost difference in jeopardy. If anticipated demand is close to the breakeven point of the alternatives, other factors should decide the issue: quality, storage costs, reliability of deliveries, chance of unexpected obsolescence, etc. Thus the graph is an aid to visualization of the problem, but it does not render an automatic decision.

## CAPITAL BUDGETING

The flow of funds in an organization has to be watched and scheduled as rigorously as materials and labor. Most demands for capital arise from plans for expansion, a need to replace existing facilities, and operating expenses. We saw the necessity of the early allocation of funds for later operations in the budgeting example of Universal Supply Services. Larger organizations face the same problems for operating capital plus the strategic need to ration funds for new investments in machines and buildings, promising research projects, enticing advertising campaigns, bargains in raw material procurement, and many other attractive but cash-consuming proposals. Someone has to decide which ones to nourish and which to starve.

Most proposals for modest investments in physical assets or special projects originate in the operating departments. Each department collects the facts and figures to support its proposals. Guidelines are normally available to ensure a complete description and substantiation. Both limits on the amount of money that can be requested and a minimum return expected from the investment screen out the less promising or unrealistic proposals. A committee of department heads, with advice from appropriate staff officers, frequently conducts another screening. Selected proposals are then submitted to higher offices where the final budget is set by consolidating all requests and evaluating their total effect on operations.

The initial outcomes of a proposal are relatively easy to estimate and substantiate. But some of the more subtle angles are easy to overlook. Production advantages of a new machine are usually conspicuous. Besides higher output, savings from reduced scrap, less material handling, and higher quality are customarily apparent. Even new costs of support services, supervision, and floor space may be discovered. But less related or longer-range considerations may be neglected: an increase in the pay required for operators, a decrease in productivity during installation and operator training, the need to increase investments in raw material or inventory before sales increase commensurately, insurance and taxes, and the cost of having money locked into accounts receivable or physical assets. Such costs are seldom conspicuous but they are still costs.

### Immediate Comparisons

How much should be paid to an operator (Y) who produces 10 pieces per hour on the same type of machine used by another operator (Z) who produces 20 pieces per hour at an hourly wage of \$5.00? A first impression might be that operator Y should be paid (10/20) × \$5/hr = \$2.50/hr. Assume the burden rate (overhead, depreciation, taxes, maintenance, etc.) for the machine is \$15 per hour. Then the cost per piece produced by operator Z would be

$$\frac{\$5/\text{hr} + \$15/\text{hr}}{20 \text{ pieces/hr}} = \frac{\$20}{20 \text{ pieces}} = \$1 \text{ per piece}$$

For operator Y to meet the same cost per piece when his output rate is 10 pieces per hour, his hourly wage (W) would have to be

$$\frac{W + \$15/\text{hr}}{10 \text{ pieces/hr}} = \$1/\text{piece; then } W = \$10 - \$15 = \underline{\underline{-\$5/\text{hr}}}$$

which means he should pay \$5 per hour for the privilege of working.

While this example is exaggerated, it does call attention to the workaday problems that confront managers and eventually show up in budgets. These problems are characterized by their immediacy. All the factors of the decision environment which influenced his decision are already present. Conditions are assumed to be certain; that is, whatever risk may be involved is ignored. And time is not a factor in immediate comparisons because the events compared occur within a short time span. The primary concern in immediate comparisons is to be certain that the choices being compared produce equivalent outcomes or that the difference in outcomes is accounted for.

### Time and Money

When the outcome of a budgeting decision involves a cash flow stretching beyond a year into the future, the time value of money has to be considered. Everyone is aware that a dollar received today is worth more than a promise of a dollar to be delivered a year from now. In addition to the practical facets of the transaction which include the chance of default by the borrower and deflation lessening the dollar's buying power, a dollar today is worth more because it can earn interest during the year. If the dollar is invested at an interest rate of 6 percent, it increases in value to \$1.06 by the end of the year. Though the powerful cumulative effects of interest and interest rates are striking when spotlighted, they are easily overlooked for relatively small or short investments.

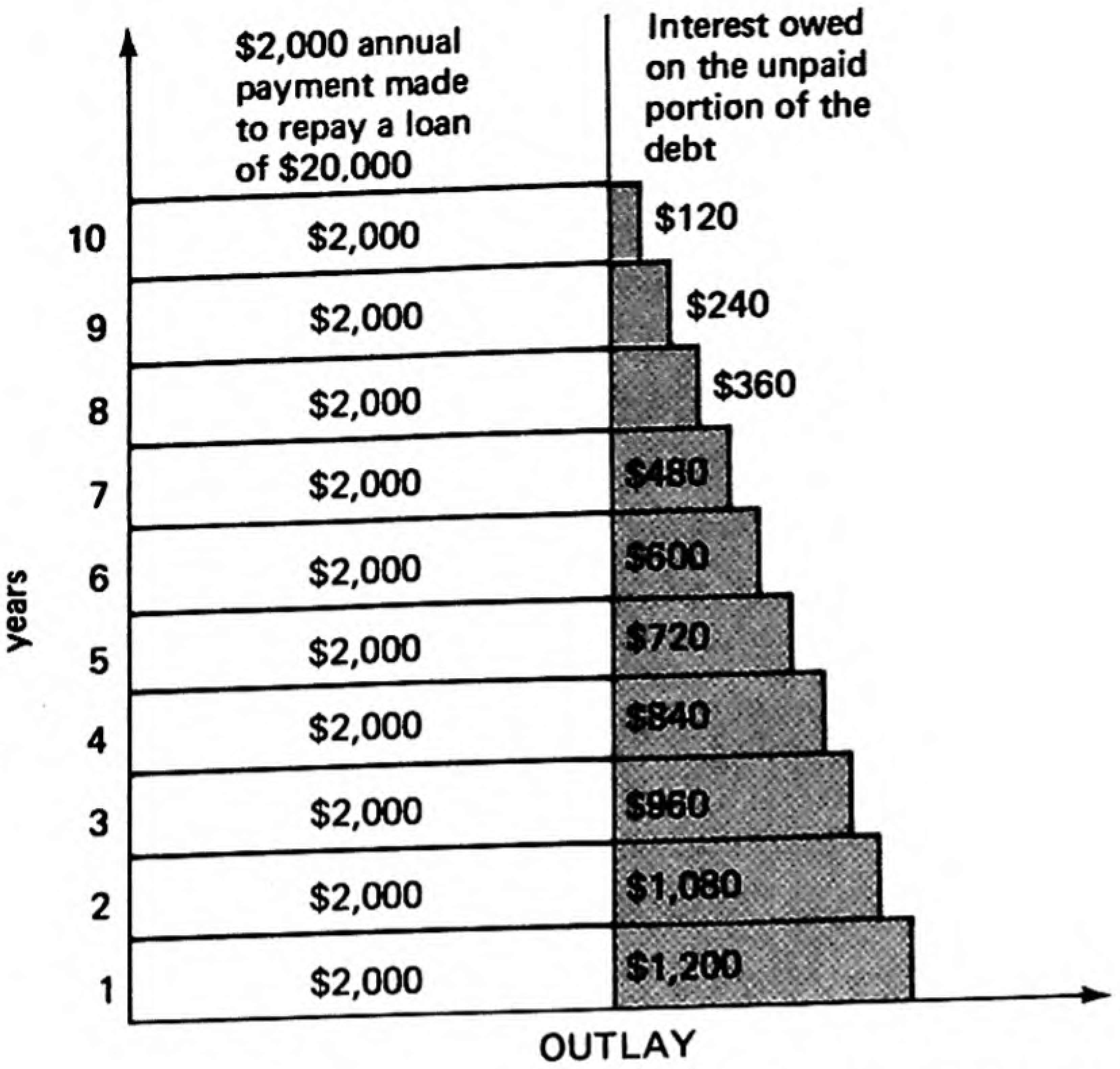


*Fig. 4-5. Repayment pattern of a 10-year, $20,000 loan with annual interest of 6% on the unpaid balance. The total amount paid for interest during the period equals $6,600.*

To observe the nature of interest, we can again use Universal Supply Services as an example. Recall that Mike Miller launched his operations by borrowing $30,000 and using $21,000 from his savings. We will consider the influence of each source of capital separately.

His loans are both an obligation and an opportunity. He must expect to repay the loans or suffer a damaged reputation, loss of possessions, and other consequences. By borrowing he has been allowed to undertake the business adventure he wanted, an opportunity that would not have been available without the use of someone else's money. But he has to repay it plus interest for the privilege of use. The loan of $20,000 from the former owner was not in cash. It was for property, but it has to be repaid in cash from operating income. Assuming a repayment period of 10 years and an annual interest payment of 6 percent on the unpaid balance, the pattern of debt retirement is shown in Figure 4-5.

The money Mike Miller withdrew from his savings to put into USS should also be expected to earn interest at a higher rate than it was earning wherever it was previously invested. A portion of the $21,000 put into USS was set aside to cover operating expenses and the rest paid for inventory and other assets. These uses were suggested by the budget in Table 4-2, but no mention was made of the interest, unless it is read into the net annual profit of $10,000. Actually, if an interest rate of 6 percent is applied, $1,260 (21,000 × 0.06 = $1,260) of the net profit is owed to Miller as a normal return for his investment. The interest he would have earned if the money was still invested elsewhere is a theoretical business expense. The health of a business is partly indicated by the rate of return it earns on internally invested capital compared to external investment possibilities.

As Mike Miller undoubtedly came to realize, interest is a very significant part of financial planning. The opportunity to borrow allows instant satisfaction of material wants, but this luxury of timing carries an additional price tag over the long run due to interest owed. Equivalently, waiting to make a purchase until enough funds have been accumulated avoids the added charge for interest, and even allows some interest to be earned during the saving period. In effect, *interest owed* is the price of not having to wait and *interest earned* is the reward for letting someone else use your accumulated savings. The former is a cost of operations and the latter is income. Both aspects must be considered in all capital investment proposals.

### Investment Comparison Methods

The first phase in the process of getting a proposal funded is proof that the organization will benefit from the proposal's acceptance. Proposals should

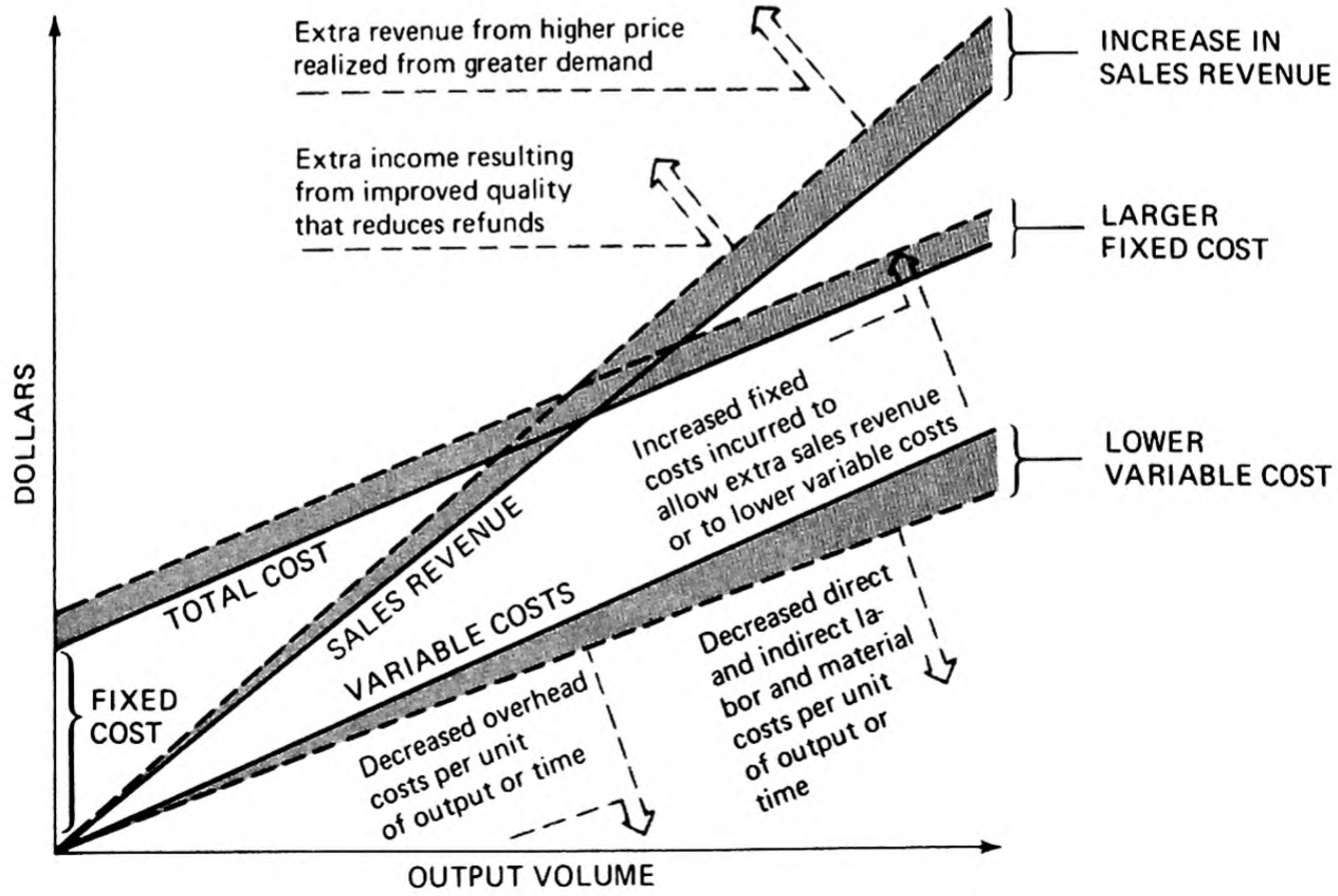


*Fig. 4-6. A breakeven chart showing probable results of proposals to raise income or reduce costs by increasing fixed charges.*

increase revenue or decrease operating costs as shown in Figure 4-6. In this version of a breakeven chart (refer to Figure 4-2 for the more traditional version), fixed costs are shown above the variable cost line. This position emphasizes how changes in revenue or cost are typically accompanied by an investment in physical property, which in turn raises fixed charges. The basic measure of acceptability for a proposal is a comparison of projected fixed cost increases with projected profit increases. A crude comparison would result from charting revenue and total cost to see what effect changes have on the breakeven point. Better methods such as the payback period and present worth are described in the following sections.

The second phase in the funding of a proposal is to rank the projects that passed the first phase. The need for ranking arises from the availability of more worthy projects than there is money for them. Ranking proposals would be unnecessary if (1) no initial investment was required or (2) sufficient capital was available to fund all legitimate proposals. The first condition was considered earlier as a problem of *immediate comparison,* and the second is so rare that it can generally be ignored. Proposals must therefore be rated by some means to guide top management's appraisals. Three methods of evaluation are offered in the following sections. Since each has advantages and weaknesses, it is important to evaluate the evaluation methods.

**PAYBACK PERIOD.** Many versions of the *payback* or *payoff* method are in use. All of them determine the period of time over which the expected annual dollar advantage from a proposal will return the capital required to obtain the advantage. The general formula for calculating the payback period is

$$\text{Payback time in years} = \frac{\text{net investment}}{\text{net annual operating advantage}}$$

The formula above is widely applied. The intent is to show the time required for an investment to "pay for itself." A shorter payback period is presumedly more desirable because it does not commit chunks of capital for extended times and indirectly protects investments against the chance of losses from new technological developments. Another reason for this method's wide acceptance is its simplicity; just divide first cost by annual savings and compare the answer to a magic number that says the proposal is good or bad. As a preliminary screen, this crude approach is reasonable. Different classes of investments can be assigned a cutoff number such as two years for production equipment, five years for buildings, etc. Then proposals obviously out of line with the payback criterion can be dropped before they receive expensive study.

Weaknesses of the payback method stem from its disregard for both the timing of cash flows and the amount of earnings received after the investment has been recovered. The timing is significant for the reasons discussed earlier; dollars spent or earned today have more value than the same inflow or outflow in the future. The importance of earnings beyond the payback period are evident from an example. Assume two machines can provide the same annual $1,000 net reduction in operating costs. Machine A costs $1,000 and will last two years before it needs to be replaced. The first cost of machine B is $1,200 but it will not have to be replaced for three years. Both machines are assumed to exhibit a constant decrease in value over their life (straight line depreciation) to a zero salvage value.*

$$\text{Payback period}_{\text{machine A}} = \frac{1000}{1000 - \frac{1000^{\dagger}}{2}} = \frac{1000}{500} = 2 \text{ years}$$

$$\text{Payback period}_{\text{machine B}} = \frac{1200}{1000 - \frac{1200}{3}} = \frac{1200}{600} = 2 \text{ years}$$

According to the payback comparison both machines are equally attractive. But a quick look at the net inflow and outflow of funds over a six-year period (the lowest common multiple of two and three years is six) reveals machine B produces a net gain of (6 × $1000) − (2 × $1200) = $3600 while machine A's net gain is only (6 × $1000) − (3 × $1000) = $3000. The $600 difference is due to the failure of the payback method to consider the earnings from an expenditure after the investment has been recovered.

**AVERAGE ANNUAL RETURN.** Another convenient method of comparing alternatives is to subtract the average cost of the investment from the net annual operating advantage. The alternative with the highest return is preferred.

In calculating the return, the net annual operating advantage is obtained by subtracting operating expenses such as maintenance and labor from savings expected from adopting the proposal. Average investment cost is the sum of the annual decrease in the value of the asset, typically the difference between the first cost and the salvage value divided by the number of years the asset will be economically sound, and the average investment multiplied by an appropriate interest rate. Thus

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*Salvage value of a machine is its market value at any point in time. Normally, the term implies the machine's net value at the end of its estimated life. If the cost of its removal exceeds its market price, the salvage value is negative.

†Machine A loses half its value ($1000/2 yr = $500/yr) each year. This charge must be deducted from the operating savings it provides to give the net annual operating advantage.

$$\begin{aligned}\text{Average annual return} &= \text{net annual operating advantage} - \text{average investment cost}\\ &= (\text{annual savings} - \text{annual operating costs})\\ &\quad - \frac{\text{first cost} - \text{salvage value}}{\text{estimated life}}\\ &\quad - \left(\frac{\text{first cost} + \text{salvage value}}{2}\right)(\text{interest rate})\end{aligned}$$

Using the data for machines A and B from the example given for the payback period, we know the net operating advantage for both machines is \$1,000. Assuming a 10 percent interest rate is the cost of capital for the firm, we have

$$\text{Average annual return for machine A} = 1000 - \frac{1000-0}{2} - \left(\frac{1000+0}{2}\right)(0.10) = \underline{\underline{\$450}}$$

$$\text{Average annual return for machine B} = 1000 - \frac{1200-0}{3} - \left(\frac{1200+0}{2}\right)(0.10) = \underline{\underline{\$540}}$$

Machine B is the apparent winner by the average annual-return criterion. The main contrast between this method and the payback method is that the fund flow for the whole life of the investment is considered. Another distinction is the inclusion of an interest factor. Although the time value of money is crudely calculated, it is at least a recognizable expense. A more thorough treatment of cash flow is provided by the next comparison method.

**PRESENT WORTH.** The accurate way to evaluate the value of future cash flows is by discounting—using an interest rate to determine the present worth of future sums. The procedure is just the opposite of the compounding process mentioned earlier. We then observed that a dollar invested today at 6 percent interest will be worth \$1 × 1.06 = \$1.06 in one year, \$1.06 × 1.06 = \$1.124 in two years, \$1.191 in three years, etc. The reverse of this compounding sequence is that \$1.191 to be received or paid three years from now has a value of \$1 today; that is, allocating a dollar now is equivalent to allocating \$1.191 three years from now.

The tedious manipulations required to convert future money into present money is eased by the use of compound-interest tables. An abbreviated table for 10 periods (*n*) for interest rates (*i*) of 6, 10, 15, and 20 percent is provided in Table

4-4. To determine how much $1,000 to be received five years hence is worth today when money can earn 10 percent interest, simply read down the $i$ = 10 percent column to the $n$ = 5 row and obtain the *present-worth factor* of 0.621. Then multiply this factor by $1,000 to get $621, the present worth.

TABLE 4-4. TABLE OF PRESENT-WORTH FACTORS FOR CALCULATING THE PRESENT VALUE OF FUTURE SINGLE PAYMENTS. FACTORS IN THE TABLE REPRESENT THE PRESENT WORTH OF $1.00 DISCOUNTED $n$ PERIODS AT THE GIVEN INTEREST RATE.

| **Period** | **PRESENT-WORTH FACTORS** | | | |
|---|---|---|---|---|
| **($n$)** | **$i$ = 6%** | **$i$ = 10%** | **$i$ = 15%** | **$i$ = 20%** |
| 1 | 0.943 | 0.909 | 0.870 | 0.833 |
| 2 | 0.890 | 0.826 | 0.756 | 0.694 |
| 3 | 0.840 | 0.751 | 0.658 | 0.579 |
| 4 | 0.792 | 0.683 | 0.572 | 0.482 |
| 5 | 0.747 | 0.621 | 0.497 | 0.402 |
| 6 | 0.705 | 0.564 | 0.432 | 0.335 |
| 7 | 0.665 | 0.513 | 0.376 | 0.279 |
| 8 | 0.627 | 0.467 | 0.327 | 0.233 |
| 9 | 0.592 | 0.424 | 0.284 | 0.194 |
| 10 | 0.558 | 0.386 | 0.247 | 0.162 |

Again returning to machines A and B as described in sample applications of the payback and average annual return comparisons, we can observe some characteristics of present-worth calculations. We already know the expected net savings,

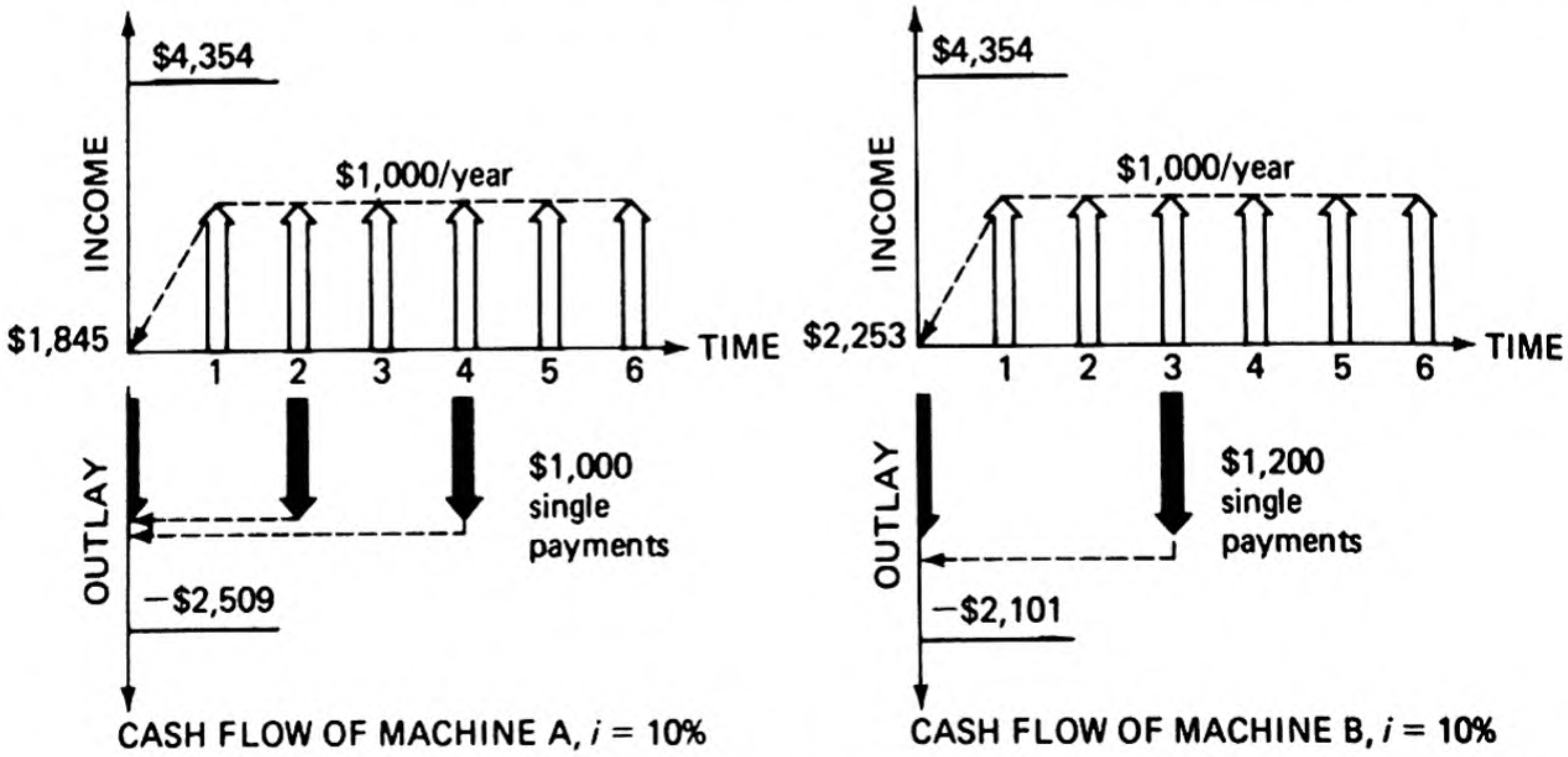

$4,354
INCOME
$1,000/year
$1,845
1
2
3
4
5
6
TIME
OUTLAY
$1,000
single
payments
−$2,509
CASH FLOW OF MACHINE A, $i$ = 10%
$4,354
INCOME
$1,000/year
$2,253
1
2
3
4
5
6
TIME
OUTLAY
$1,200
single
payments
−$2,101
CASH FLOW OF MACHINE B, $i$ = 10%

*Fig. 4-7. Discounted cash-flow diagrams comparing the present worth of two investment proposals. Machine B with its greater positive present value ($2,253) is the preferred alternative.*

first cost and life of the machines, and the interest rate. Since alternatives have to be compared on the basis of equivalent service, the study period extends to the point where assets with different "lives" have served a comparable period; six years in this case. Discounted cash-flow diagrams are given in Figure 4-7 for both machines.

The present values of the future cash flows displayed in Figure 4-7 are calculated by multiplying each payment by the appropriate present-worth factor from Table 4-4. (Tables of compound interest factors for calculating the present worth of a series of equal sums or sums increasing at a constant gradient are widely available. Multiplying by a single factor can then replace the chore of bringing each sum back to the present.)[2] Using an interest rate of 10 percent and assuming the payments occur at the end or beginning of each year, the present-worth comparison is conducted as

**MACHINE A**

| Period (n) | Cash Flow | Present-Worth Factor | Present Value | |
|---|---|---|---|---|
| 0 | −1,000 | 1.000 | −1,000 | |
| 1 | +1,000 | 0.909 | | +909 |
| 2 | +1,000 | 0.826 | | +826 |
| | −1,000 | 0.826 | −826 | |
| 3 | +1,000 | 0.751 | | +751 |
| 4 | +1,000 | 0.683 | | +683 |
| | −1,000 | 0.683 | −683 | |
| 5 | +1,000 | 0.621 | | +621 |
| 6 | +1,000 | 0.564 | | +564 |
| | | | −$2,509 | $4,354 |
| | | Net gain | | $1,845 |

**MACHINE B**

| Period (n) | Cash Flow | Present-Worth Factor | Present Value | |
|---|---|---|---|---|
| 0 | −1,200 | 1.000 | −1,200 | |
| 1 | +1,000 | 0.909 | | +909 |
| 2 | +1,000 | 0.826 | | +826 |
| 3 | +1,000 | 0.751 | | +751 |
| | −1,200 | 0.751 | −901 | |
| 4 | +1,000 | 0.683 | | +683 |
| 5 | +1,000 | 0.621 | | +621 |
| 6 | +1,000 | 0.564 | | +564 |
| | | | −$2,101 | $4,354 |
| | | Net gain | | $2,253 |

The figures above again confirm the preference for machine B over machine A. Although the choice is clear, the degree of preference could be misconstrued. It pays to remember that future cash flows are forecasts; if the actual annual operating advantage for machine B proved to be $900 instead of the estimated $1,000, the choice would switch to machine A. By testing how sensitive the solution (preference) is to possible forecasting errors, a manager is more likely to give due attention to important but difficult to quantify *intangible considerations.* Particularly in cases where one alternative has a very narrow edge over another one, intangibles such as the spirit of the workforce, appearance of an installation, or opinions of interested parties may sway a verdict to a slightly more expensive but more satisfying solution.

There are two other ways besides the present-worth method to make discounted cash-flow comparisons. The *annual cost method* compares the equivalent annual costs of proposals computed with a given interest rate. The *rate of return* method determines an interest rate that equalizes positive and negative cash-flow streams within a proposal. The resulting rate of return is the interest rate earned by money invested. Which of the three basic discounted cash-flow models to use is largely one of personal choice. All three will indicate the same final preference when the same input data are used. All incorporate the time value of money. They are powerful tools to assist the evaluation of major capital allocations and consequently deserve care in application.

### Comparison Precautions

The selection of a comparison method may decide which alternative is selected. We observed how the payback method indicated no preference between machines A and B while the other comparison methods favored B. Some offbeat method from the many available might even indicate a preference for A. Always relying on discounted cash-flow comparisons eliminates this disturbing feature. It takes a bit longer to perform discounted cash-flow calculations, but the greater realism and consistency make the effort worthwhile.

Comparison methods that account for the time value of money are generally applauded, yet there is no agreement as to what rate of interest is the right one to use in discounted cash-flow calculations. Should it be the current rate for borrowing from an independent source, the present rate the firm earns on its capital, the rate it would like to earn, or what? Ideally the interest rate to use in evaluating a specific proposal would be the actual cost of acquiring capital to implement the proposal. But the costs of seers and sleuths needed to ferret out the information for each proposal would be prohibitive. The use of an interest rate based on average charges made to tap the most common sources of funds is a convenient trade-off between practicality and perfection.

It's foolish to ignore risks in estimating capital budgeting. Savings and expenses for an entirely new type of venture are always hazardous guesses. Sometimes changes in technology make even an estimate of a salvage value for a familiar machine difficult. Identification of increases in revenue derived from a single piece of equipment operating in the midst of all other production equipment is perplexing. A reasonable device to differentiate requirements for riskier investments is to adjust the required general interest rate upward for differing degrees of cash-flow uncertainty among competing alternatives. The amount of adjustment relies on the experience and judgment of management, as do all budgeting decisions.

## REFERENCES

W. Rautenstrauch and R. Villers, *The Economics of Industrial Management*, Funk & Wagnalls Company, New York, 1949.

James L. Riggs, *Economic Decision Models for Engineers and Managers*, McGraw-Hill Book Company, New York, 1968.

# SECTION 2
# SYNTHESIS

Science is built of facts
the way a house is built of
bricks; but an accumulation
of facts is no more science
than a pile of bricks is a
house.

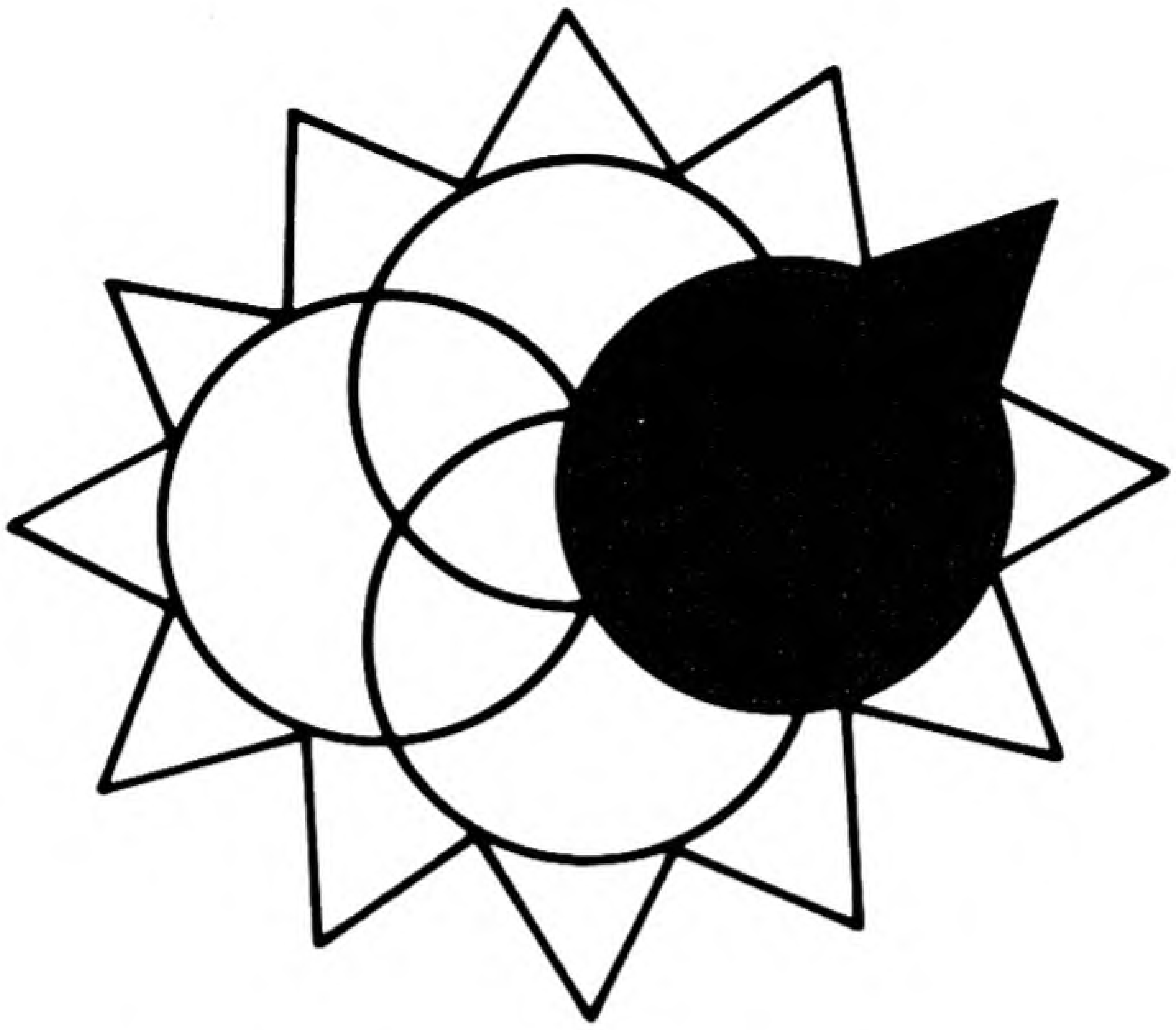
HENRI POINCARÉ
*La Science et l'hypothèse,*
1902

We use the facts revealed by analysis by drawing conclusions from them. In organizations the conclusions are usually management decisions. Put another way, a decision is a synthesis which takes facts from cause-and-effect relationships to form principles for action. Consider an example. Suppose you are deciding whether you should keep an appointment you have made. You can analyze the situation by studying why you made the appointment and what will happen if you keep it or not. Once you determine the facts, you arrange them in patterns to evaluate the consequences and make a decision: show or no show.

Synthesis is seldom effective unless it is preceded by a good analysis, and an analysis is an empty exercise unless the revelations are used. Thus analysis and synthesis are lock-step functions, but in major applications they frequently overlap because significant questions often have multiple objectives and nonsequential considerations. For example, in deciding where to locate a new office, the criteria for selection could initially include building costs, transportation access, and neighborhood atmosphere. Site selection analysis would include investigating all the factors that affect the criteria. Some potential sites would be dropped from consideration when analyses reveal their inadequacies. Finally the attributes of the sites remaining in contention would be compared. Relevant considerations for each site would be combined to produce a composite impression or rating. Possibly the comparisons would lead to additional criteria requiring another cycle of analyses. Then a new synthesis of data would create a refined rating for the sites.

As management tools and techniques are presented in the chapters of this section, consider how they contribute to more complete managerial assessments. Chapter 5, "Planning," focuses on the inputs, particularly forecasting, involved in the development of long- and short-range plans. Chapter 6, "Scheduling," describes how scheduling techniques, particularly network methods, can assist the systematic integration of activities to accomplish planned objectives. Chapter 7, "Operating," emphasizes work measurement, productivity, and working conditions as factors in the operating environment that contribute to the overall proficiency of production.

# Chapter 5



# Planning

**KEY SUBJECTS**

*Planning is a state of mind, a process, and a collection of procedures used to integrate activities.* To "plan your work and work your plan" is sound advice for all managers. Initial planning efforts should be aimed at critical problem areas and be limited both in detail and range.

The first phase of planning is to ascertain present conditions, to recognize areas of strength and areas of weakness. Goals of the organization are identified and analyzed in the second phase. The final phase is to construct a plan based on the preceding phases. It must include measurable criteria of accomplishment to control performance. The planning period should extend far enough into the future to foresee the consequences of present decisions. Plans based on conflicting objectives, too narrow a scope, or an overly short planning horizon seldom work well.

*Operations planning emphasizes short-range activities of departments and individuals.* Supervisory personnel are the key to cooperation and control at the production level.

*Forecasts of future demands are necessary inputs to planning.* Predictors can be derived from subjective opinions, analysis of historical records, or evaluation of underlying causes. Which forecasting method to use depends on the purpose of the forecast, quality and quantity of data available, and the ultimate usefulness of the results.

*Historical data can be graphed or analyzed mathematically to identify a pattern that provides an indication of future events.* Line fitting, exponential smoothing, and moving averages are widely used techniques of analysis. Each technique can be evaluated by examining how well it would have predicted past events.

*Forecasts based on cause range from relatively simple correlation comparisons that identify a leading indicator to very elaborate mathematical models that relate many contributing causes.* Causal forecasts are most valuable in predicting a turning point in demand.

## PLANNING PERSPECTIVES

Everyone gives lip service to planning. Children plan fun on picnics. People plan vacations. Students plan vocational careers. Housewives and office workers plan their day's activities. Supervisors plan the work to be done by others. Managers develop plans to improve productivity. Businesses plan to make a profit. The effort put into planning ranges from daydreaming to diagraming. Resulting schemes range from the fanciful to the factual. There are occasions for both extremes; management planning is one of the serious occasions.

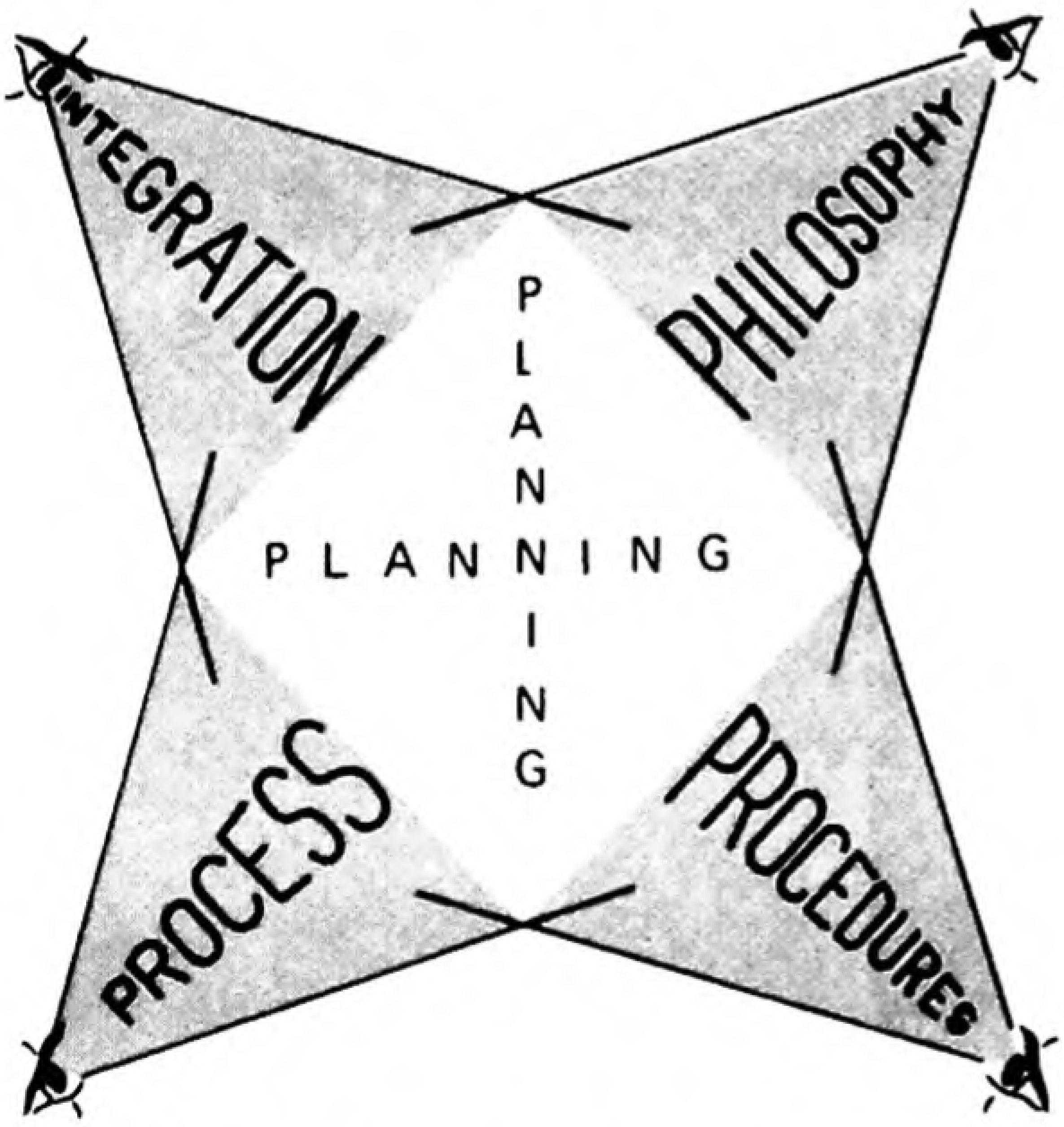


*Fig. 5-1. What a planner sees as "the planning function" depends on which view he takes. All the views are accurate. Which one dominates in a specific planning effort depends on the scope, stage, and aim of the planning effort.*

Planning has several dimensions. In preceding chapters we observed many factors that contribute to the planning function. The way these factors and others fit together under the collective title of *planning* is implied by Figure 5-1 and the following views of the planning function.

1. *Planning is a philosophy.* Looking ahead is a way of thinking, a concern about the future effects of today's actions. Planning involves a state of mind that recognizes the need for orderliness and the value of direction. Individual planners may sway between optimism and pessimism, but they dare not stray too far from reality.
2. *Planning is an integration.* Both long- and short-range plans provide a unifying structure to give purpose to the organizational units involved. Broader plans consider the supplies, customers, and other peripheral contacts of an enterprise. More detailed plans set the framework for coordinated activities within an enterprise. Together they constitute a projection of overall expectations and an explanation for individual contributions.
3. *Planning is a process.* Goals and objectives are the most obvious consequence of the planning process. A loose objective of survival or of making a profit is a fuzzy guideline, clearly inadequate for steering an enterprise. A winning plan includes the strategy that defines how much has to be done to achieve the objectives, the sequence of events that satisfies those strategies, and the assignments that lead to the accomplishment of the events.
4. *Planning is a collection of procedures.* All companies plan ahead to some extent and apply their own methods in doing so. In a small company, one man may do it all. Larger companies often have standard procedures for formulating and carrying out plans. Forecasting specialists, planning sections that collect and digest data, scheduled meetings at different organizational levels to solicit suggestions and to inform participants, and control measures to check progress contribute to complete planning procedures. Limited procedures are enough for simple plans; more elaborate procedures are required for complex plans.

## PLANNING PATTERN

"Plan your work and work your plan" is old advice that is as appropriate today as when it was coined. It suggests that accomplishments are attained by patiently figuring out the best way to do something and then checking to see that the devised scheme is followed. Admittedly the best way may not be discovered initially, but it is difficult to detect a better way when there is nothing for comparison. Even a sketchy plan is better than no plan because it provides a basic pattern for detection and evaluation of glaring deviations, good or bad.

Planning tends to be a continuous activity with spurts of frenzy for special occasions, such as the end of a planning cycle and after a major catastrophe or bonanza. In larger organizations planning schedules and procedures are routinely followed as a vital part of doing business successfully. Smaller organizations often lack such pat routines. By surveying problems that accompany the adoption of a planning program, we can more easily observe a program's ingredients.

### Planning Problems

A young, growing company could be guided by nothing more than rainbow glimmerings in the minds of the managers, seeking success and pursuing it ambitiously without defining it. New organizations that survive are typically founded to serve a specific customer need. To stay healthy they must adapt as customers' needs change. Adaptations can be painful with inadequate planning. Yet initial successes enjoyed without expending effort in formal planning can lull managers into complacency. It may take a serious setback to arouse them.

Even after a young organization becomes dedicated to planning, many problems have to be overcome. The planning program must reach down to the operating level to be effective. Administrative personnel can identify goals and lay out schedules, but operating personnel are the ones who carry out the schedules. Knowing how and why the schedules were developed can increase the enthusiasm and cooperation of all levels. By including more people in planning sessions, better familiarity with the plan is ensured but such democratic planning sessions easily get bogged down in cross-currents of personal interests.

How comprehensive the planning should be is another question. Smaller organizations seldom can afford the luxury of inclusive plans, even if they possess the time, experience, and operating data needed to develop such plans. In some ways less comprehensive plans are an advantage during a company's adolescence. Managers might be less responsive to changes when operations are tightly structured, and quick reaction time is vital to such organizations. The pioneering spirit of a new company could suffer from more exactly defined goals. Disillusionment might result because benefits from comprehensive planning do not come immediately. Some managers get trapped by the misconception that once they have a plan, the anticipated benefits will automatically follow. They conveniently forget the need to "work the plan."

For initial planning efforts, you should make a modest beginning that concentrates on key business aspects deserving special attention. Suggestions for launching a planning program include

1 Selecting a currently critical problem area. More enthusiastic participation in planning is assured when the planners know the importance of their work.

2. Not attempting too much detail. Any significant problem has roots that extend into many related areas. Define only the most important ones and try to avoid controversial issues that are not intimately involved with the main issue. Resulting plans will detail only the principal elements and then rely on managers to fill in the gaps with day-to-day decisions.

3. Limiting the plans to short-range proposals. The range should extend to a logical evaluation point that is still within the forecasting competence of the planners. The practice gained in formulating and implementing short-range plans should provide the expertise needed for future long-term planning.

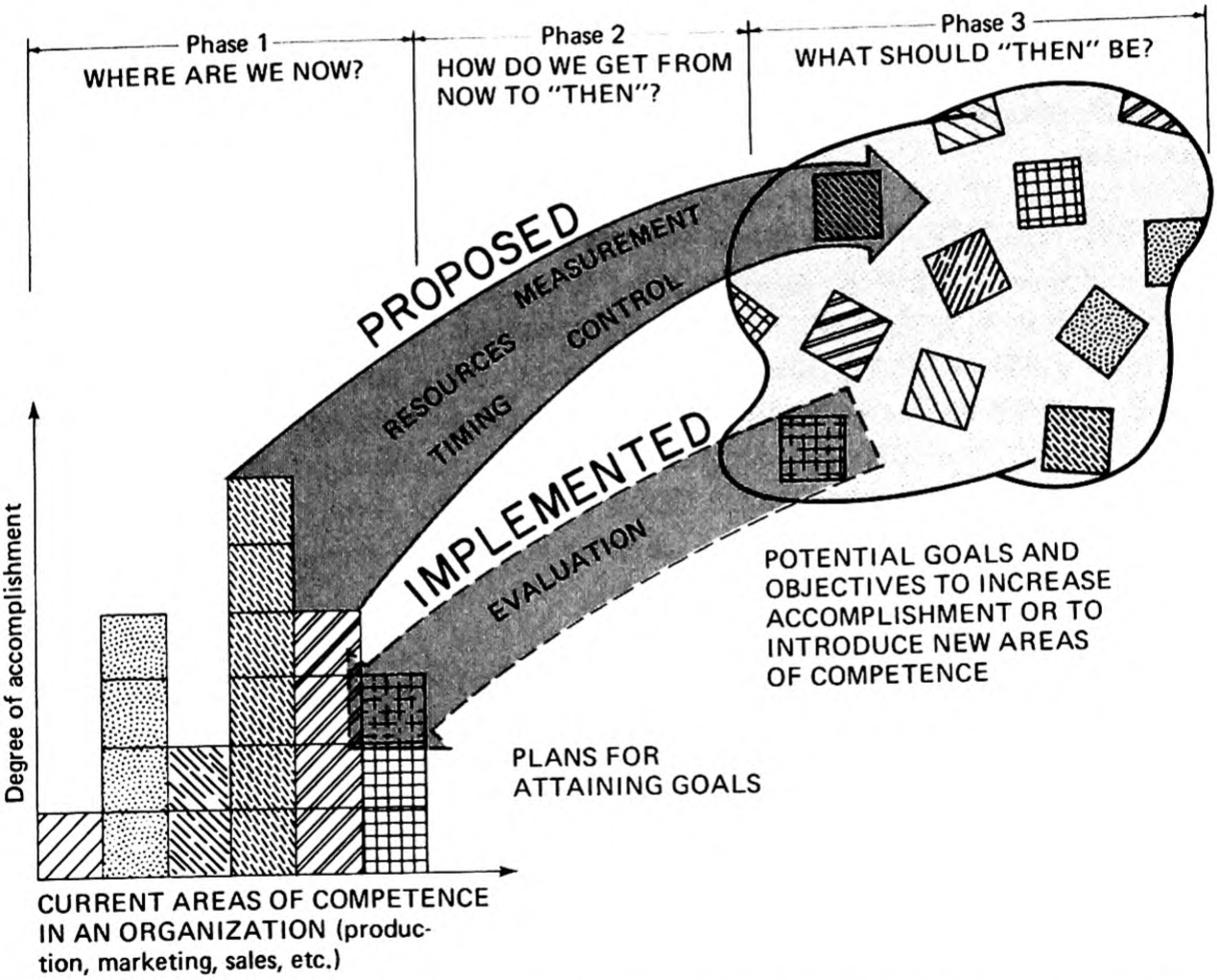

Phase 1
WHERE ARE WE NOW?
Phase 2
HOW DO WE GET FROM NOW TO "THEN"?
Phase 3
WHAT SHOULD "THEN" BE?
PROPOSED
MEASUREMENT
CONTROL
RESOURCES
TIMING
IMPLEMENTED
EVALUATION
POTENTIAL GOALS AND OBJECTIVES TO INCREASE ACCOMPLISHMENT OR TO INTRODUCE NEW AREAS OF COMPETENCE
PLANS FOR ATTAINING GOALS
Degree of accomplishment
CURRENT AREAS OF COMPETENCE IN AN ORGANIZATION (production, marketing, sales, etc.)

*Fig. 5-2. In every organization there are "steeples of excellence." After determining, first, the state of each area of competence and, second, which objectives to pursue, plans may be made to achieve these objectives. Proposed plans should take into consideration resource allocations, timing of events, and measurements required for control. Cooperation among several areas is usually needed to implement a plan. Once the planned objectives have been achieved, results should be evaluated to determine better measures for future control.*

### Planning Plans

Figure 5-2 outlines activities involved in developing a plan. The *starting point* is to determine where you are right now. Planners are often shocked to find that previous plans have not been fully realized and their organization is not nearly as well prepared as they believed. This condition is especially likely when the planning session is devoted to correcting a current or expected problem. At the opposite extreme is the condition where extraordinary competence in a certain area is overlooked in planning future activities.

Most organizations have "steeples of excellence"—groups or departments exhibiting superb performance. The value of steeples in a localized area lies in their "aura effect" through which internal interactions tend to raise the overall quality of performance. Externally the steeples build a reputation that enhances the whole organization. Steeples also influence planning. Particular areas of expertise can support ventures in areas of less competence and provide offshoots into new areas at a more refined level. The prominence of the steeples, however, can bias planning by the temptation to improve already distinguished resources.

The *second phase* of planning is the identification and analysis of goals which the organization seeks to accomplish. Profit seeking is surely a necessary goal for survival of a business firm, but it is certainly not the only goal. A profitable firm would not last long if the organization failed to satisfy its customers, to respond to the needs of society, to obey legislated regulations, or to meet the expectations of its employees. Similarly, nonprofit organizations should continually upgrade their service excellence. Good planning by service agencies identifies future needs of society in order to have new services available as soon as they are required.

A firm can chase innumerable objectives. Selecting the most appropriate ones depends heavily on an appraisal of present conditions. If survival is a key issue, the immediate goals might be to meet upcoming debt payments or maintaining a minimum cash balance for satisfying payrolls and material purchases. A healthy business might seek to increase its market share or raise productivity. When operating conditions get uncomfortable, objectives could be to enhance public opinion or to conform to new conditions such as pollution control. All logical goals should be analyzed for their immediate consequences, lingering effects, compatibility with overall priorities, and the way specific assignments harmonize departmental operations.

Construction of the plan is the *third phase,* although consideration of its structure began in the two earlier phases. Assignments to operating units spring from the survey of present potential and the expectations inherent in the goals.

For example resources are allocated according to the timing and priority of the selected objectives.

A vital aspect of a finished plan is measurable standards by which to evaluate accomplishments. Some physical and financial measures are easy to formulate: rate of return, amount of output, number of acquisitions, inventory turnover, etc. Other goals such as the development of workers and execution of social responsibilities are very difficult to quantify. Methods for measuring difficult to quantify characteristics are treated in Chapter 13. The importance of setting measurement standards is most evident when the time arrives to evaluate how well the goals were met. Without means to measure performance there can be no effective control over execution. Without control the chance of attaining a goal diminishes rapidly.

## POLICY PLANNING

According to the dictionary,[1] *policy* is "1. political wisdom or cunning; diplomacy; prudence; artfulness. 2. wise, expedient, or crafty conduct or management. 3. any governing principle, plan, or course of action." Managers acting in a policy-making role must be very wise indeed to meet the standards set by definitions 1 and 2. The third definition suggests the critical nature of policy making in an organization; it establishes the basic direction for all subsequent operational planning.

### Planning Horizons

Policy planning may extend decades into the future or only a few months ahead. Whether plans covering a given period are classified as long, short, or intermediate is immaterial because the opportune planning period varies with the type of organization, level, and purpose. As a general rule, *the planning period should extend just far enough into the future to include the consequences of present decisions.*

A planning period that is not long enough to cover the evaluation of a project or one that stretches far beyond the time a project is completed loses much of its value. Too short a period does not allow for adequate measurement of goals. For instance, a plan to increase productivity by the introduction of automated equipment should have a horizon far enough into the future to include the replacement point at the end of the equipment's economic life. Conversely, extending the planning horizon to more than one replacement cycle introduces the largely unnecessary risk of forecasting far distant events. Extra-long planning horizons may add surface elegance to the planning function, but it is doubtful if the increased complexity is accompanied by equivalent added usefulness.

### Suboptimization

Policy making deals with strategic alternatives—designs for achieving significant goals involving major resource commitments. We observed earlier that an organization seldom has a single, overriding goal. Several compatible goals are sought at the same time. It is relatively easy to maintain a complementary relationship between goals, but it is frequently difficult to design a plan to implement one goal that does not in some way conflict with plans to achieve other goals. This conflict situation is an example of *suboptimization*—a condition that satisfies immediate objectives while violating strategic goals.

Suboptimization becomes most apparent when tactics are developed to carry out strategic plans. "You don't understand the big picture" is a common re-

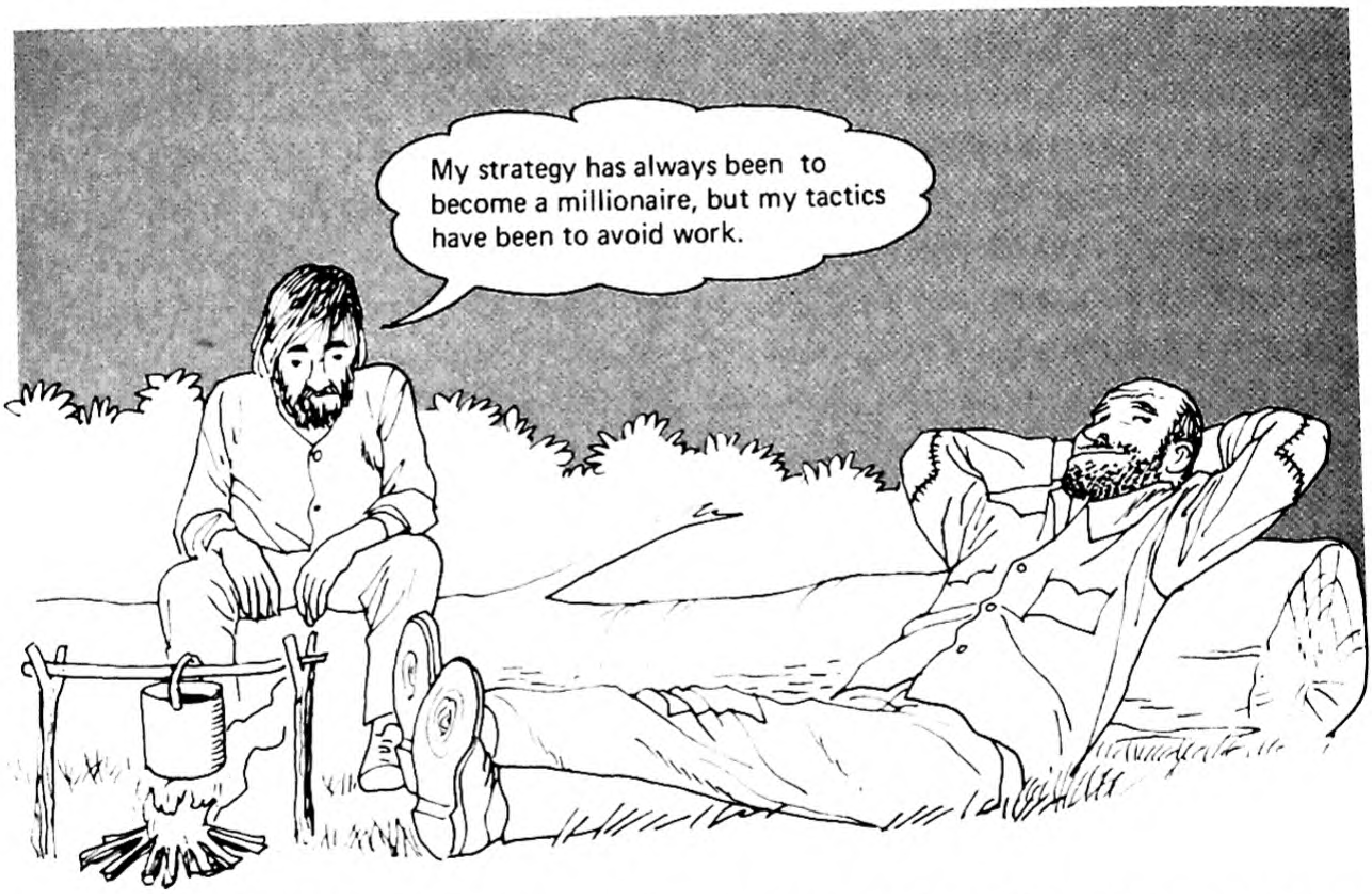

My strategy has always been to become a millionaire, but my tactics have been to avoid work.

*Fig. 5-3. Both organizations and individuals can be confused by opposing objectives. For example, in a company, confusion could result if one product in a family of related products had poor sales, and to save the ailing product, company resources were redeployed. The rescue of the weak product might succeed but the other products in the family could suffer reduced sales because of the drain on resources; thus, the battle would be won but the war lost.*

*Individuals seeking "the good life" also get caught by conflicting goals. If "good" is interpreted as "long and full," then unlimited pleasure-seeking for a full life would undoubtedly jeopardize health needed for a long life. Moderation, however, should produce a temperate plan to satisfy both goals, resulting in a life less full but longer.*

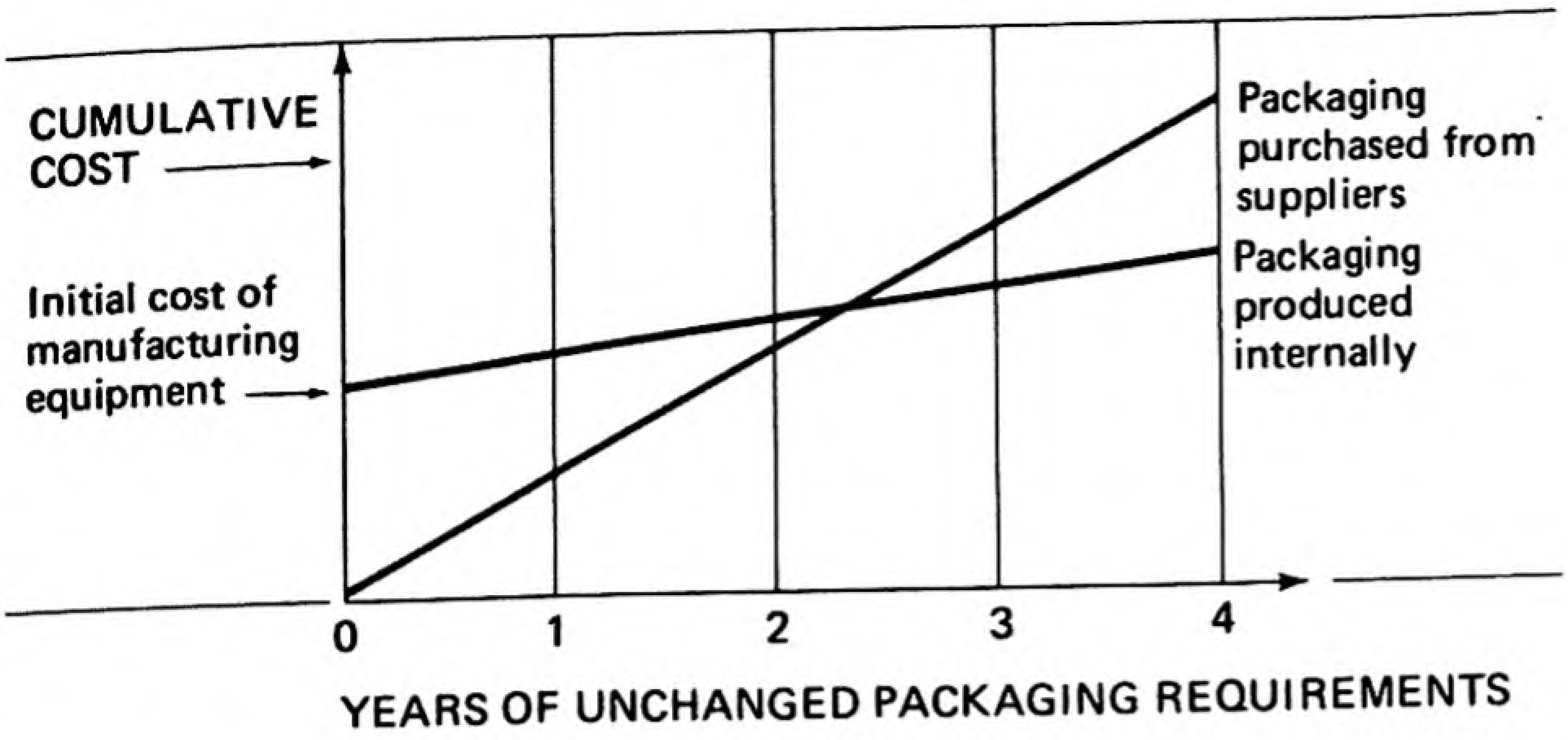


*Fig. 5-4. Suboptimization, caused by not looking far enough ahead in making a decision that will affect operations over a long period of time, is nicely pictured by the "make or buy" chart above and the breakeven graph of Fig. 4-5 in Chapter 4. In both cases a short planning horizon (2 years for Fig. 5-4) would dictate purchasing the packaging, but a longer planning horizon that anticipated continued use of the same packaging would switch the choice to producing it. Individuals face the same danger of suboptimization in lease-or-buy decisions for housing and transportation.*

sponse from harried managers to many seemingly sound proposals to alleviate an operating problem that would, if adopted, clash with policies established for the overall benefit of the organization. Three regularly encountered forms of suboptimization are (1) conflict of interest (methods) as in Fig. 5-3, (2) shortsightedness (see Fig. 5-4), and (3) tunnel vision (see below).

Organizations are very susceptible to situations in which departments understand the common goal but individually go about working toward the goal in ways that hurt each other. A typical example is the goal to reduce material and inventory costs as viewed by

- *Purchasing* "Buy in large quantities to get quantity discounts."
- *Comptroller* "Buy in smaller quantities to avoid paying interest on the capital required for the purchases."
- *Production* "Larger inventories allow longer production runs which reduce manufacturing costs."
- *Warehousing* "Larger inventories cost more to store and increase the cost of material handling."

If each of the involved departments acts independently, inventory levels will behave like a yo-yo. Obviously, a workable plan will be a compromise, probably satisfying no one completely, but still producing lower total material costs for the organization as a whole.

## OPERATIONS PLANNING

Policy planning lays out the route; operations planning tells how to travel. Strategy sets the dates; tactics give the hourly schedule. Developing policy objectives is an exercise in futility unless they are translated into detailed operating plans. The translation process descends through many organizational levels as the broad outlines are converted to specific assignments. Eventually the plan commits all the resources—men, money, materials, and machines. Not everyone needs to know the plan in its entirety, but each should know his assignment and what part it plays in the plan.

An appreciation for good operations planning comes from examining the results of bad planning. Results are most apparent at the front line of management, where the product is built, service is rendered, or clients are helped. Characteristics of poor planning at the factory floor level are

- materials not available when needed because requisitions were tardy, delivery was made to the wrong place, or allotted amounts were insufficient
- equipment is not available because it is broken down, already assigned to another project, or has never been obtained
- men are untrained or not available
- supervision is lacking because group leaders are not aware of the project or do not understand it

When such conditions occur the workers lose confidence in their leaders. Morale drops because workmen cannot be sure of their earnings, become disinterested in their work, or get frustrated at fellow workers. Labor turnover rises, usually among the best men. Even worse, the loss of confidence may lower expectations to the point where workers accept inefficient operations as normal.

All the conditions mentioned can be reduced or eliminated by effective operations planning. The routine for planning operations is similar to strategic planning, only the scope is smaller. At the supervisory level the emphasis is on cooperation and control. Basic objectives to coordinate departmental functions are part of policy planning that should include input from supervisors. Specific directions to meet the objectives are developed within the departments or divisions by supervisors and managers. Broad considerations include

1. means to handle departmental assignments within imposed time limits and at the expected level of accomplishment
2. coordination with other departments to use resources best

3. readiness to help other departments when disruptions occur or to continue operations during unforeseen emergencies

More specific actions by a supervisor include

1. keeping abreast of the current capabilities and expected performance of the men, machines, and materials within his domain
2. selecting men and equipment to meet the needs of specific situations
3. developing schedules and routing patterns to accomplish assigned missions
4. following up to determine whether the plan is working successfully, making changes if it is not

The planning horizon for most supervisory action is only a few days, but supervisors should have information about longer-range policies to allow them to anticipate more distant events. Capacities of workers, methods and materials used in production, and equipment requirements change with time. Not only must supervisors know about current conditions for immediate plans, they must match the changes they observe with prospective requirements of future operations. Training programs may be necessary or equipment might have to be adapted to a new process. Different materials need testing and new work methods may be necessary. Close attention to short-range planning of operations combined with forethought about future operations avoids wasted energy and makes the work of all those involved more satisfying.

The importance of good planning at the supervisory level cannot be overemphasized. A relatively ineffective policy can still be salvaged by efficient supervisors, but even a superb policy cannot compensate for weak supervision. The purpose of top-level planning, directly or indirectly, is to assist supervisory activity in producing the output on which the organization thrives. The directives that emerge to guide the workforce are the measures of success for the whole planning effort. As Henri Fayol said, "If foresight is not the whole of management, at least it is an essential part of it."[2]

## FORECASTING

A planner has to face the realities of the present while keeping his eyes on the future. The prediction of future events that can affect strategic goals and tactical operations is the function of forecasting. It involves both art and science. The simplest form of forecasting is a mental voyage into the future to guess what might occur. Experienced guessers can do amazingly well. More disciplined forecasting methods utilize statistics and formal procedures to draw conclusions about future events from past events. Regardless of the methods employed, the basic issues are to predict the type, level, and resource requirements of activities that will occur during the planning period.

Both the importance and the difficulty of forecasting are very visible. Look at the many uses of a sales forecast, the basic prediction for commercial organizations. How much to produce, how large an inventory to accumulate, when to expand, what products to push, what prices to set, and a host of other decisions are based on sales expectations. When a direct cause-and-effect relationship exists between the amount of sales to expect and some identifiable measure (for instance, gift shop sales might rise or fall in direct proportion to the reservations made at a resort), then accurate forecasts are in prospect. To expect comparable accuracy in most other situations is unrealistic. There are too many variables. However, even a distorted window into the future is better than no window at all (see Figure 5-5).

Attempts to seek a competitive edge from a glimpse into the future are nothing new. Rulers in the Middle Ages had their favorite crystal gazers and fortune tellers. Today astrologers and palm readers have believers, including some businessmen. Other organizational leaders rely on market surveys, product questionnaires, and quantitatively trained forecasting experts to anticipate levels of future activity. Yet no forecasting technique is infallible. Even the overwhelming amount of timely data about current conditions and advanced com-

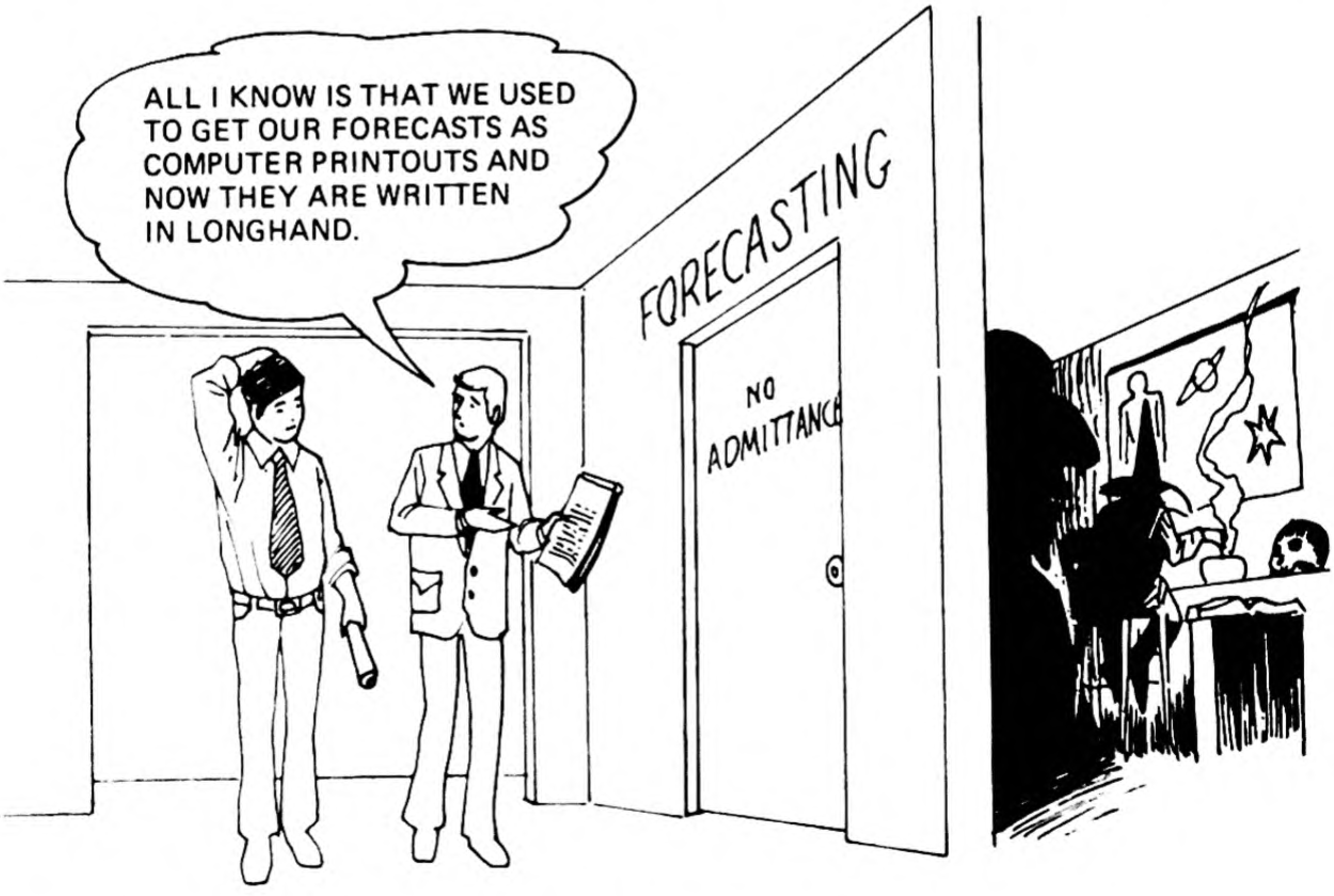

ALL I KNOW IS THAT WE USED TO GET OUR FORECASTS AS COMPUTER PRINTOUTS AND NOW THEY ARE WRITTEN IN LONGHAND.
FORECASTING
NO ADMITTANCE

*Fig. 5-5. There is more than one way to tell or seek a fortune.*

puter analyses now available cannot ensure accurate forecasts. Just ask any weather forecaster.

There are many ways to develop predictions. For convenience in getting an overview of the methods available, they can be grouped in three categories: (1) subjective, (2) historical, and (3) causal. Several methods falling within the three categories will be discussed in later sections. In appraising which method to use in a given situation, consider the following factors

1. **PURPOSE OF FORECAST.** Highly accurate forecasts are needed for operations planning to schedule manpower and to allocate material or equipment. Conversely, only a general sketch of future activity is necessary for preliminary investigations of new product possibilities. More precise predictions are more expensive to make. It would be financial foolishness to allocate the same money and effort to a situation where a gross estimate will suffice and one where greater accuracy leads to greater savings. Figure 5-6 shows the relationship of forecasting costs and forecasting errors.

2. **DATA AVAILABILITY.** Lack of data, such as historical information about a firm's operations, restricts the types of forecasting techniques that can be used. Also, some techniques can make better use of available information than

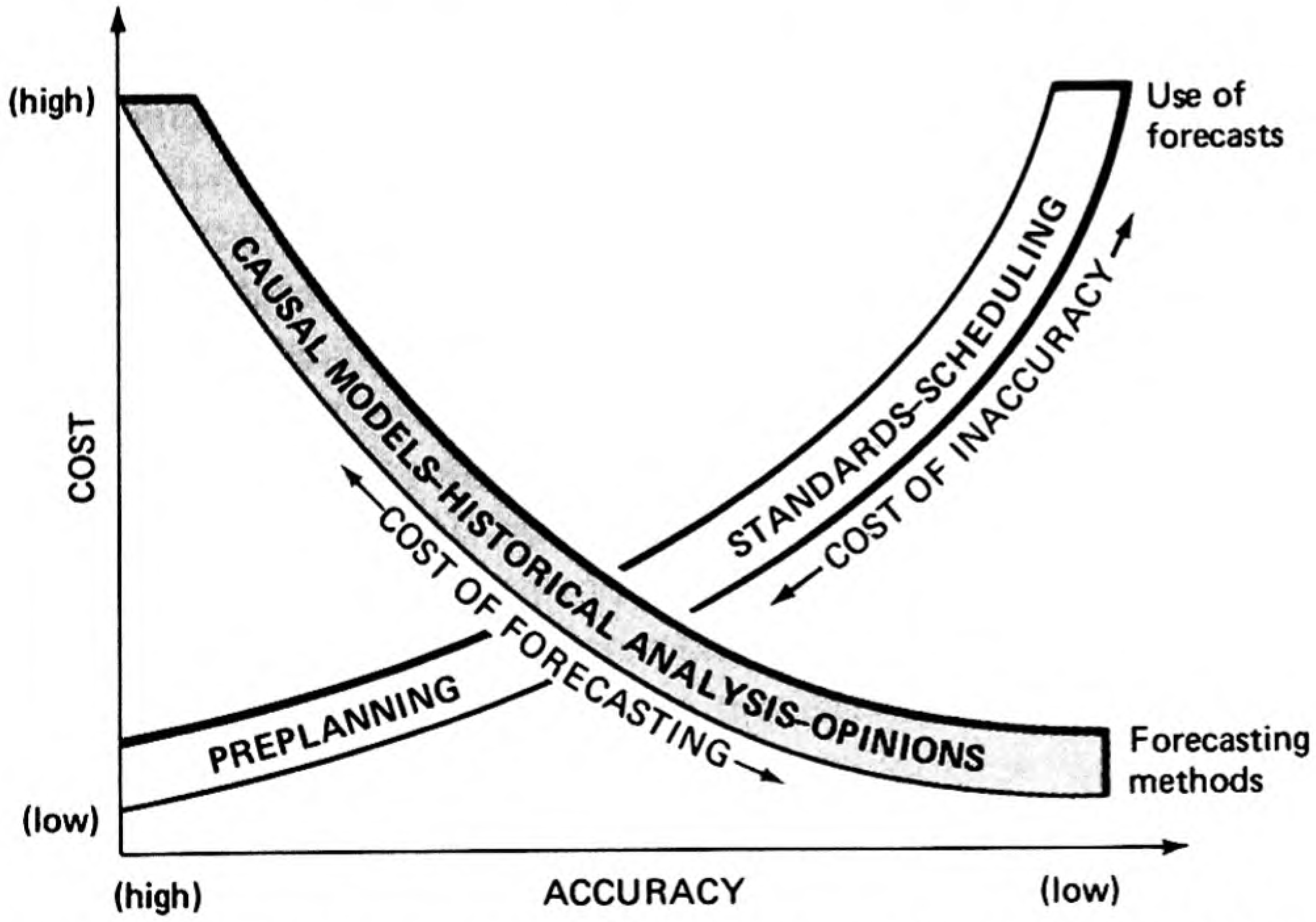


*Fig. 5-6. A method of forecasting must be justified by its economic feasibility. More sophisticated techniques should produce more accurate predictions. Since the total cost of an activity includes both the expense of making a forecast and the cost of damage resulting from inaccurate forecasts, more funds should be allowed for predictions upon which expensive activities will be based.*

others. If information is expensive to secure, the cost aspects displayed in Figure 5-6 are pertinent.

3. **QUALITY OF DATA.** The quality as well as quantity of data should be assessed because the most elaborate forecasting method cannot extract valid predictions from defective data. New economic, political, or technological conditions can make previously useful data obsolete. Inaccurate data can be especially harmful when they slip by everyone's attention. It is useful to employ two or more forecasting methods in parallel as a check on each other.

4. **USEFULNESS OF RESULTS.** A forecast has very little usefulness unless the prospective user has confidence in it. The simpler forecasting methods often appear more reliable to laymen because they can understand how the predictions are arrived at. Accurate forecasts quickly build confidence; conversely, inaccurate ones quickly destroy trust. Timeliness is related to accuracy. A correct prediction that is arrived at too late to contribute to planning has slight value. Ideally, the method used should be understood by all users, should be revised whenever accuracy declines, and should produce reliable forecasts with a minimum elapsed time between data evaluation and the prediction.

## FORECASTS BASED ON OPINIONS

Unfortunately, persons who make predictions may let their personal feelings take command over what they know are facts. We call predictions based on feeling *subjective,* and we term the ones based strictly on fact *objective.* Some years ago a young man went to an unfamiliar area to invest in a chain of coin-operated car washes. He sought advice on the investment and was put in touch with a man who had considerable experience in the automotive field; he had been a mechanic, an automotive service manager, and the operator of a taxi company. The young man asked him, "What do you think of the possibilities for success of a chain of coin-operated car washes in this area?" Now this man had a particular aversion to any mechanical device for cleaning the finish of a car. He simply didn't believe that it was good for the finish to use pressure hoses, mechanical scrubbers, spray waxers, etc. He did believe in hand washing with sponge and chamois and in hand waxing and polishing. As a result, his answer was, "Those coin-op car laundries are a flash in the pan. They'll never have any success around here."

It so happened that the facts indicated the opposite. Sales of new cars, personal incomes, traffic counts, population growth curves all would have said yes to the young man's question. That particular area was one in which vast quantities of salt were used on the roads in the winter. This fact alone leads many people to wash their cars frequently in coin-operated washes. Now there are several hundred of these car-wash units in the area. The sad part of the story is that all these coin-ops are operated by some owner other than the original young man. The prediction which he got was based upon subjective rather than objective information.

Personal opinions are not necessarily bad sources of advice. In many instances they are the only source of forecasts. Even when more objective sources can be called upon, opinions may offer valuable insights or provide extra assurance about a prediction. Many companies routinely seek opinions from people who buy or sell their products. Four formal methods of obtaining subjective information are described below.

1. **CONSUMER SURVEY.** A person who has actually bought a product is the most logical source of information about that product's sales appeal. Questions to the buyers are often part of a product's guarantee. Follow-up questionnaires are frequently mailed to purchasers of a large item, such as a car. Sometimes surveys are made of potential rather than actual consumers. Replies from this audience have to be interpreted carefully because consumers' tastes change very rapidly, and what a customer intends or hopes to do in the future may be far removed from what he does.

2. **OPINIONS OF SALESMEN AND DISTRIBUTORS.** An experienced sales force is in a position to observe both the actions of suppliers and the behavior of consumers. They can give warnings about changes in buying trends and the activities of competitors. The optimism or pessimism of individuals of the sales force can be balanced by averaging the predictions made by several salesmen and sales managers.

3. **EXECUTIVE VIEWS.** Many forecasts used by executives are made by executives. The effect of individual biases is reduced by generating forecasts as a group effort. The mixture of interests and experience, however, that ensures a good cross-section of estimates makes a consensus difficult to obtain.

4. **MARKET TRIALS.** The most elaborate means of gathering consumer opinions is to try selling a new product on a trial basis. The trial is designed to be a carefully controlled experiment. The small market area is selected to represent as realistically as possible the whole market the product will compete in. Care is taken to avoid obstructing competition and to be sure the results are timely. Since the cost of these experiments is high, market trials are limited to significant product promotions.

## FORECASTS BASED ON HISTORICAL RECORDS

Basing forecasts on historical evidence relieves most of the uneasiness connected with relying on personal opinions. Historical data are simply facts. It is up to the forecaster to make interpretations from them. He can, of course, introduce his own bias into the interpretation, but this bias is open to exposure because the facts from which the forecast was drawn are still available for reexamination. In addition to the factual attractiveness of historical data, two adages bear out the value of past performance to estimate future performance: *History repeats itself* and *we learn from experience.*

### Line Fitting

The most direct way to observe historical patterns is by plotting data on a time scale. A quarterly sales record for 10 years is plotted in Figure 5-7. The purpose of graphing is to expose a recurring shape or pattern that gives a clue as to where the next point or series of points should fall. The assumption that existing patterns will continue into the future is more likely to be correct over a short- rather than a long-planning horizon, unless the patterns are unusually stable.

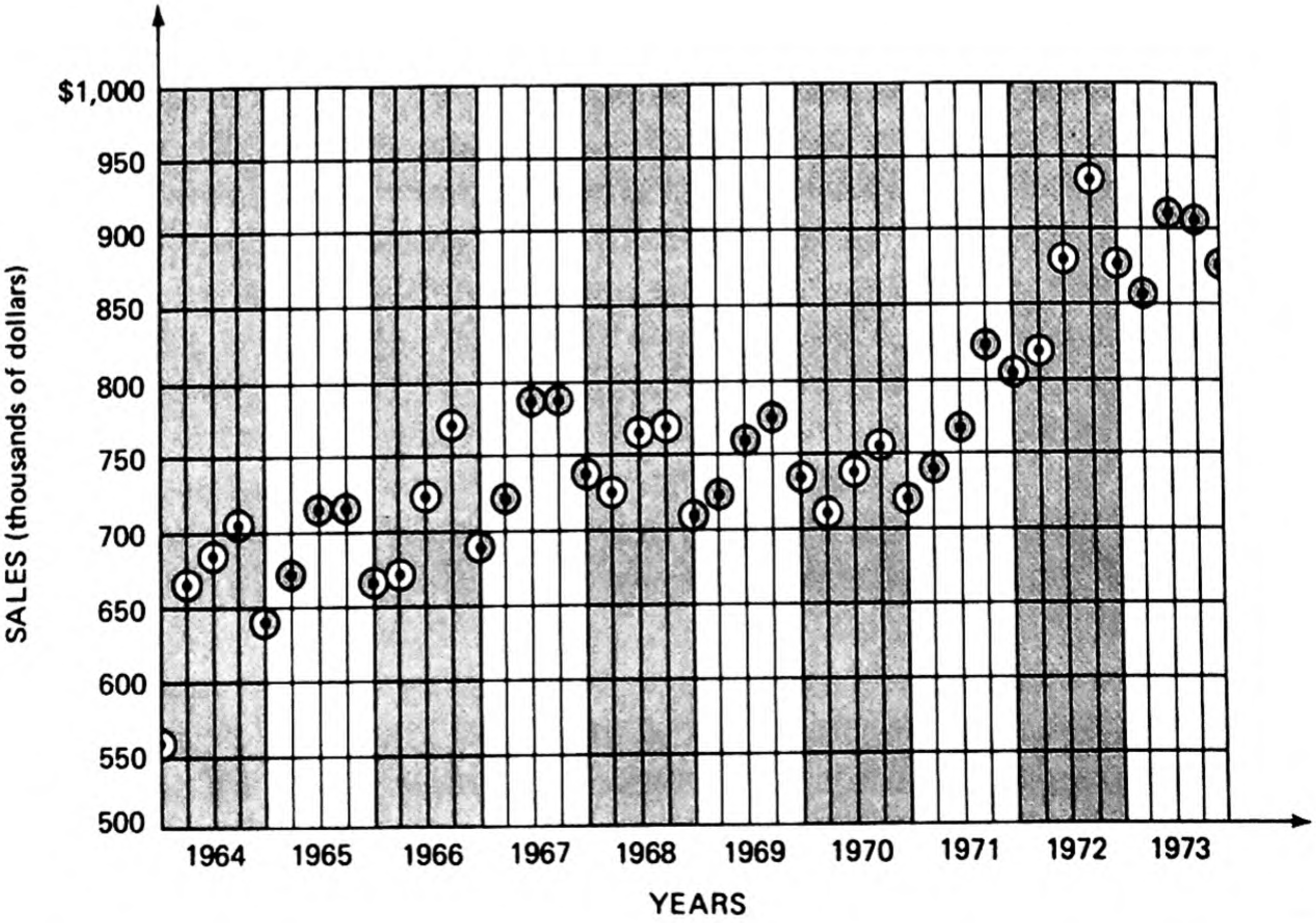


*Fig. 5-7. Ten-year record of sales.*

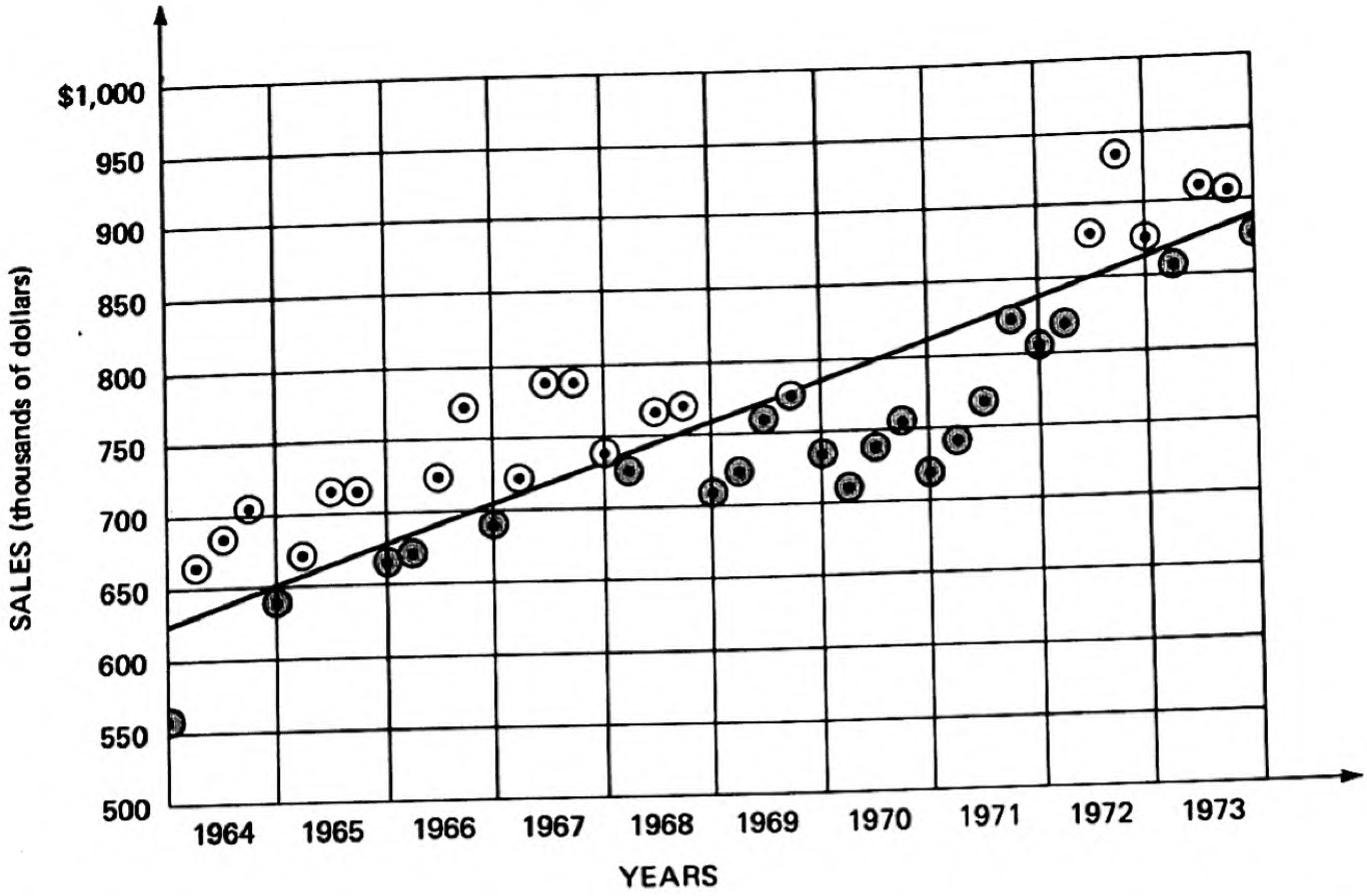


*Fig. 5-8. Long-term trend line imposed on the sales data from Fig. 5-7. The trend line shows the general direction of sales during the decade 1964–1973.*

The scattered sales-level dots from Figure 5-7 are repeated in Figure 5-8 with the addition of a *trend line*. This straight line is constructed to show the *long-term trend* in sales. It can be sketched freehand or fitted mathematically by use of the *least-squares* method. By either method, roughly half the dots should be above the line and half below. The best possible fit exists when the sum of the squared distances of each dot to the line is smaller than the sum of the squared distances from any other line that might be drawn. By applying the least-squares method, the formula for the trend line shown is Sales ($) = $625,000 + $26,500*X*, where *X* is the number of years in the future from the base year 1963 for which an estimate is sought. For instance, the sales level indicated by the trend line for year 1973 ($X = 1973 - 1963 = 10$) is

$$\begin{aligned} \text{Sales}_{\text{end of 1973}} &= 625{,}000 + (26{,}500)(10) \\ &= 625{,}000 + 265{,}000 = \underline{\$890{,}000} \end{aligned}$$

Similarly, the forecast for 1974 would be

$$\text{Sales}_{1974} = 625{,}000 + (26{,}500)(11) = \underline{\$916{,}500}$$

Even a crudely fitted trend line is revealing. An upward slope for the given scales of years and dollars suggests still higher sales figures for future years. A downward slope would, of course, indicate the opposite. The closer all the dots are clustered around the line, the higher the confidence that a true trend has been identified. It is intuitively logical that a history of widely surging sales suggests a future with wide fluctuations; in this context a forecast for a specific level of sales would not be greeted with much assurance.

Historical data may also reveal *cyclic patterns* within the long-term trend. Two types of wavelike variations are noticeable in Figure 5-9 where the sales dots are again repeated from Figure 5-7. The large wave shows a business cycle of some sort. It may represent repeating fluctuations in local economic conditions, repeating changes in styles or consumer tastes, recurring fads and buying habits, or a combination of these and other factors.

The other cyclic pattern is attributable to seasonal variation. The insert in Figure

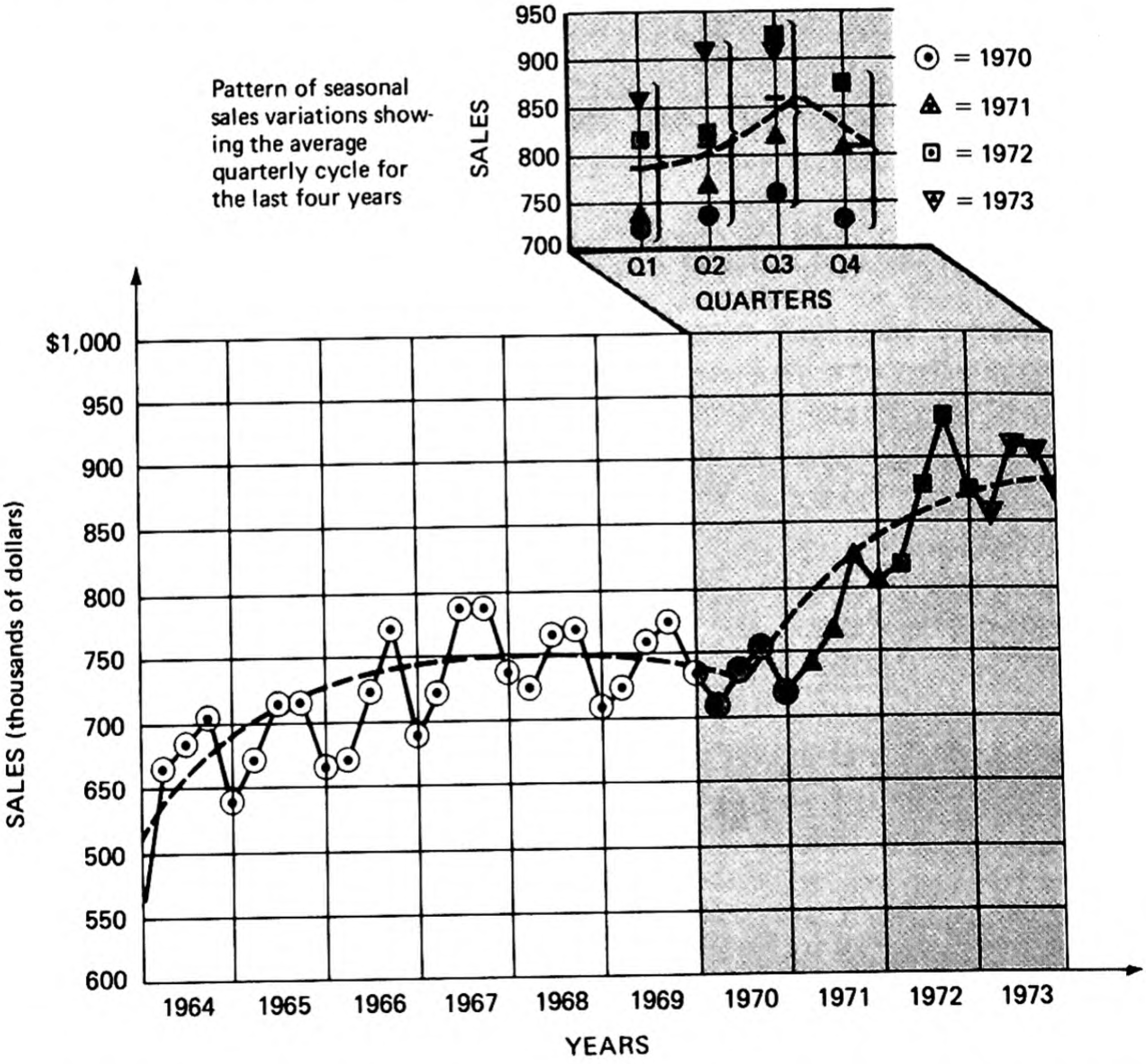


*Fig. 5-9. Business cycle and seasonal variation patterns imposed on the sales data from Fig. 5-7.*

5-9 displays the data collected in respective quarters of a year. It is evident that higher sales can be expected in the middle two quarters of each year. Many products that depend on a particular season (ski equipment, swimming wear, gardening supplies, holiday treats, etc.) exhibit a repetitive sales pattern each year.

The purpose of distilling different patterns from a collection of data is to improve the forecast. A long-term trend gives a valid prediction of the general region in which future sales should fall. (This trend is modified by cyclic influences when they appear.) The longer term cycles are difficult to identify, but the seasonal cycles are quite apparent and predictable. The forecast for 1974 from the given sales data (Figures 5-7 through 5-9) would probably be just slightly higher than the current (1973) sales with the highest demand concentrated in the middle two quarters. A forecast for 1975 and 1976 would likely predict a sales pattern about the same as 1974 due to the long-run cyclic influence. Less confidence can be placed in the forecasts as they are pushed farther into the future because new factors could enter to disrupt the traditional patterns.

### Exponential Smoothing

Line fitting gets to be a cumbersome chore when forecasts are compiled daily or weekly as in the case for many operational activities. *Exponential smoothing* is a technique devised to use past performance in a summary form to produce a forecast for the next period. It cannot be used to make predictions several periods in the future like line fitting methods, but it is very simple to apply for one period forecasts.

The exponential smoothing formula has only three inputs:

1. LD = Latest Demand—the most recent data on actual accomplishments for the subject being forecast. LD in a sales forecast would be the sales made during the current period.
2. PF = Previous Forecast—the forecast produced for the current period by applying the exponential smoothing formula. The forecast made with the LD for the current period will be the PF for the next forecasting period.
3. $\alpha$ = Alpha—the smoothing constant that has a value between 0.0 and 1.0. The value selected for $\alpha$ determines how much emphasis is put on the more recent data.

The above factors are combined as shown below to yield a forecast, NF, for the next period.

$$\text{Next forecast} = NF = a\,(LD) + (1 - a)PF$$

By algebraically juggling the above formula, we can rewrite it to show that the new forecast is simply the previous forecast corrected by adding a percentage (alpha) of how much the old forecast missed the actual demand:

$$NF = PF + a\,(LD - PF)$$

As an example, let alpha have a value of 0.4, let sales for June be 4,200 units, and let the forecast made in May for the sales expected in June be 4,500 units. Applying the two versions of the exponential smoothing formula we get

$$\begin{aligned} NF_{\text{July}} &= a\,(LD_{\text{June}}) + (1 - a)\,PF_{\text{June}} \\ &= 0.4\,(4{,}200) + (1 - 0.4)\,(4{,}500) \\ &= 1{,}680 + 2{,}700 = 4{,}380 \text{ units} \\ \text{and,}\quad NF_{\text{July}} &= PF_{\text{June}} + a\,(LD_{\text{June}} - PF_{\text{June}}) \\ &= 4{,}200 + 0.4\,(4{,}200 - 4{,}500) \\ &= 4{,}500 - 120 = \underline{4{,}380 \text{ units}} \end{aligned}$$

It is apparent from the above equations that the value used for alpha significantly affects the forecast. If alpha is set equal to zero, the original forecast never changes, no matter how much the actual demand varies from it. At the other extreme, when $a = 1.0$, the next forecast always equals the last demand experienced. A projection that the next period will be the same as the last period is extensively used for short-term production scheduling and is known as *persistence* forecasting. Between the extremes, $a$ values closer to zero produce more stable predictions that may not detect current trends, and a value closer to 1.0 closely tracks actual demands with forecasts that may fluctuate erratically.

The best way to choose alpha is to apply different values to historical data to see which one would have provided the most accurate forecasts in the past. A simulation exercise to evaluate alpha values is shown in Figure 5-10. As expected, forecasts made with higher alphas are more responsive to current demand and consequently follow the actual demand pattern more closely. Other formulas using more involved smoothing techniques can yield even better tracking, but the simplicity of record keeping, the easy computations, and the often commendable accuracy of the basic exponential smoothing formula make it attractive for tactical planning.

FORECASTS DEVELOPED FROM IDENTICAL DATA WITH ALPHA VALUES OF 0.2, 0.4, AND 0.6

| Date | Actual Demand | Forecast at α = 0.2 | Absolute Error | Forecast at α = 0.4 | Absolute Error | Forecast at α = 0.6 | Absolute Error |
|---|---|---|---|---|---|---|---|
| Oct 8 | 180 | | | | | | |
| 15 | 164 | | | | | | |
| 22 | 162 | 177 | 15 | 174 | 12 | 170 | 8 |
| 29 | 151 | 174 | 23 | 169 | 18 | 165 | 14 |
| Nov 5 | 143 | 169 | 26 | 162 | 19 | 157 | 14 |
| 12 | 158 | 164 | 8 | 154 | 10 | 148 | 10 |
| 19 | 154 | 163 | 9 | 156 | 2 | 154 | 0 |
| 26 | 160 | 161 | 1 | 158 | 7 | 154 | 6 |
| Dec 3 | 172 | 161 | 11 | 159 | 16 | 158 | 14 |
| 10 | 178 | 163 | 15 | 164 | 16 | 166 | 12 |
| 17 | 188 | 166 | 22 | 170 | 18 | 173 | 15 |
| 24 | 174 | 170 | 4 | 177 | 4 | 182 | 8 |
| 31 | 172 | 171 | 1 | 175 | 4 | 177 | 5 |
| Jan 7 | | 171 | — | 174 | — | 174 | — |
| Average Error: | | | 12.3 | | 11.5 | | 9.6 |

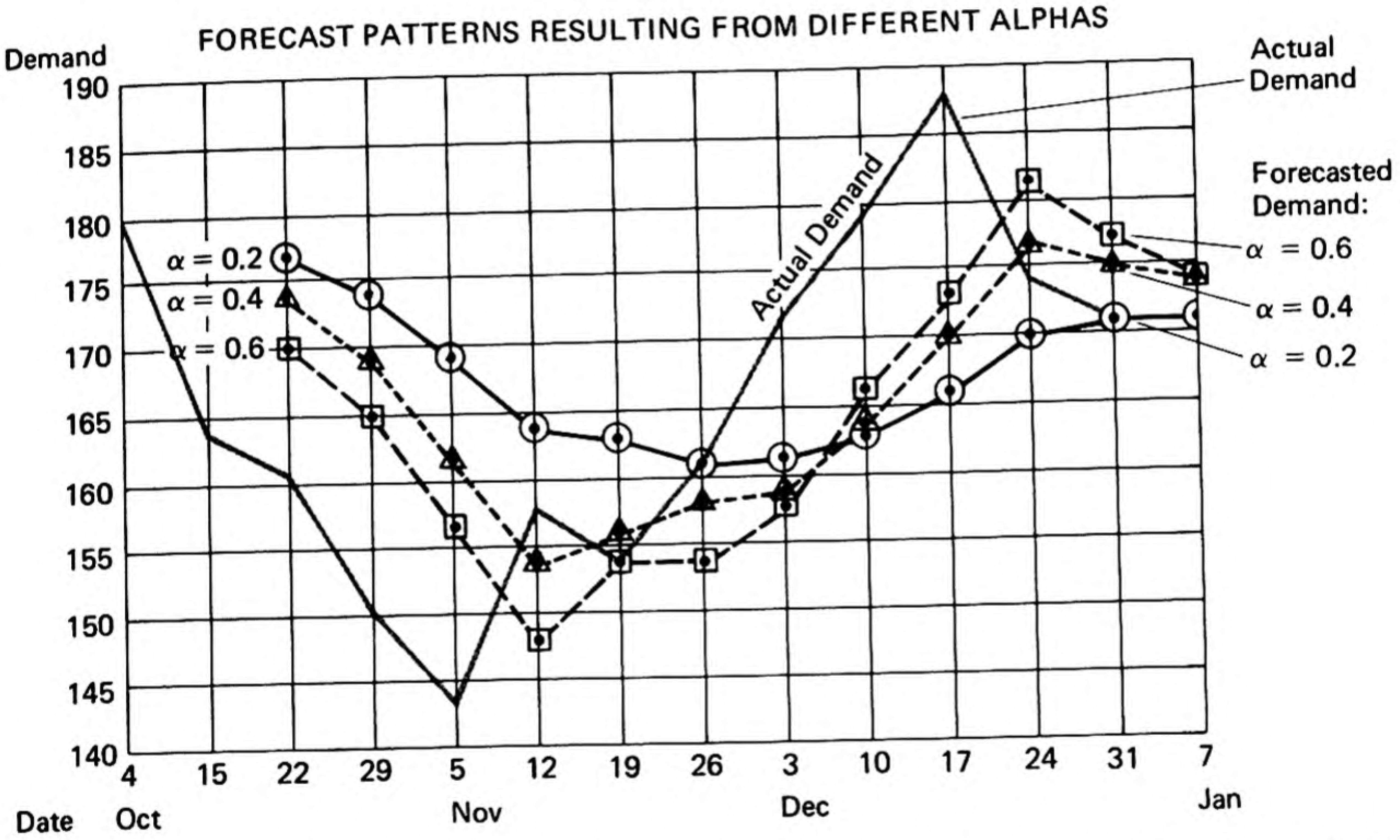


*Fig. 5-10. Comparison of forecasts provided by the exponential smoothing method using different alphas. To start the forecasting process, the first forecast is approximated by letting it equal the first demand. Thus the forecast for Oct. 22, when* $\alpha = 0.2$*, was calculated as* $NF_{Oct\ 22} = 0.2(164) + 0.8(180) = 177$*. Subsequent forecasts then include the estimate for and the actual demand in each weekly period. The graph demonstrates how the lag between forecasted and actual demand fluctuations is decreased by larger alpha values.*

### Moving Average

Another popular forecasting method predicts the demand for the next period from the average demand experienced during several recent periods. This method is called the *moving average*. It is quite similar to exponential smoothing in that both methods "smooth" or "average out" the fluctuations in past demands to produce a forecast. The main difference between the two methods is that the choice of alpha in exponential smoothing determines how sensitive this forecast is to the most recent demands, while a moving average forecast gives equal weight to each demand period included in the forecast.

A three-month moving average forecast for the next month would simply be the average demand experienced for the last three months. For example, the three-month moving average forecast for June would be calculated as

$$\text{New forecast (June)} = \frac{\text{demand (March)} + \text{demand (Apr)} + \text{demand (May)}}{3}$$

Following the same pattern, the forecast for July would result from averaging the demands for June, May, and April. The most recent block of actual demands is used in each successive forecast.

The choice of how many periods to include in the moving average involves the same considerations used to select an alpha value for exponential smoothing. A forecast based on very few periods is more sensitive to the latest events, like an alpha value near 1.0. An average derived from data taken over several periods will better reduce fluctuations caused by random events, but it may be too stable to detect current trends. As was the case for exponential smoothing, the best way to decide how much smoothing is necessary is to experiment with past demands. Try different spans for the moving average and select the one that would have predicted previous demands most accurately.

To examine further the two smoothing approaches to predicting, suppose you have secured permission to sell refreshments for theatrical performances given at the college playhouse. Besides the usual soft drinks and popcorn, you offer homemade tarts. Since the tarts have to be baked within a day of when they are to be sold and the market for stale tarts is quite limited, predicting sales is very important. The sales record for the first 10 performances is tabulated below. Each performance was a sellout and all future performances are expected to play to capacity crowds.

| Date | Jan | 5 | 6 | 12 | 13 | 26 | 27 | Feb | 2 | 3 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tarts Sold | | 120 | 120 | 120 | 144 | 191 | 171 | | 172 | 186 | 153 | 145 |

In reviewing the sales, you recall that you sold all the tarts you baked for the first four performances. Then you increased production for the remaining performances to 16 dozen (192) and started having leftovers. For the last two performances you barely covered costs because so many tarts remained unsold. Now the question is how many to bake for the next performance.

If $\alpha = 0.4$ and 192 is used as the previous forecast starting on January 27, the forecast for the last four performances would have been:

| Date | Feb 2 | Feb 3 | Feb 16 | Feb 17 |
|---|---|---|---|---|
| Exponential Smoothing Forecast ($\alpha = 0.4$) | 184 | 179 | 181 | 170 |
| Variance with Actual Demand | −12 | +7 | −28 | −25 |

By applying a three-month moving average to obtain the same historical forecasts for the last four performances, we have:

| Date | Feb 2 | Feb 3 | Feb 16 | Feb 17 |
|---|---|---|---|---|
| 3-month Moving Average Forecast | 167 | 178 | 176 | 170 |
| Variance with Actual Demand | −5 | +8 | −23 | −25 |

Since we can see how many tarts would have been left unsold using either method, some extra checking seems logical. What was the attendance at each of the performances (not necessarily the number of tickets sold)? What was the make-up of the audience (a children's program usually means more refreshments sold)? Were there any unusual conditions that might have held sales down during the last two performances? Answers to such questions may suggest inputs to forecasting that are not included in the formulas.

If no factors were found to have influenced recent sales, the formulas suggest how many tarts to bake for the next performance:

$$\text{Forecast (alpha} = 0.4) = 170 + 0.4\,(145-170) = 160$$

$$\text{Forecast (3-month average)} = \frac{186 + 153 + 145}{3} = 161$$

Both methods yield about the same forecast. It is interesting to note that an exponential smoothing forecast with $\alpha = 0.8$ produces a forecast for the next period of 148 and a six-month moving average yields a forecast of 170. The former is very sensitive to recent demands, and the latter is relatively insensitive.

From these figures you can readily see how different versions of the same formula can lead to different answers to a manager's forecasting questions. And if you can mentally put yourself in the situation described, you will appreciate the fragility of forecasting. So many factors can affect the future. Yet you have to have something upon which to base your plans. Maybe a combination of personal opinions with predictions derived from historical patterns is the preferred method. In the shadowland of predictions, a forecaster cannot ignore any signals.

## FORECASTS BASED ON CAUSE

Very reliable predictions are possible if the causes for future demand can be identified and measured. The causal approach to forecasting has produced sophisticated models that attempt to include all the relevant causal relationships; in the most elaborate models there may be hundreds of quantified relationships. But causal models can also be quite simple. Perhaps knowledge of a single cause is sufficient for predicting, as in the case of a college bookstore, which orders books based on knowledge of how many students have been admitted to the school for the next year. The manager of the bookstore could apply a factor based on past history to the number admitted to forecast his demand for supplies in the forthcoming weeks.

*Leading indicators* are frequently used in business forecasting. These indicators are statistics compiled and published by many sources: *The Wall Street Journal, Business Week,* U.S. Government reports on almost everything, local government reports on economic activity, university publications, etc. If an indicator can be found that shows what demand you can expect for your sales in, say, six months, you can plan your activities accordingly. It is even more comfortable to have two or three leading indicators pointing in the same direction. The problem is to find the accurate indicators.

A search for a reliable indicator starts with assumptions as to what causes the demands you want to predict. A house builder could hypothesize that housing demand depends on local population growth, prices for houses, personal incomes, demolition of old houses, and housing starts by competitors. After possible indicators have been collected, they can be checked by line-fitting methods. An acceptable indicator has a pattern similar to the historical demand pattern, but leads it by several time periods. Whether or not the numerical values of the indicator are higher or lower than the demand being forecasted is unimportant; only the pattern counts. After the pattern has been revealed, a conversion factor can be determined to relate the magnitude of the indicator to the demand.

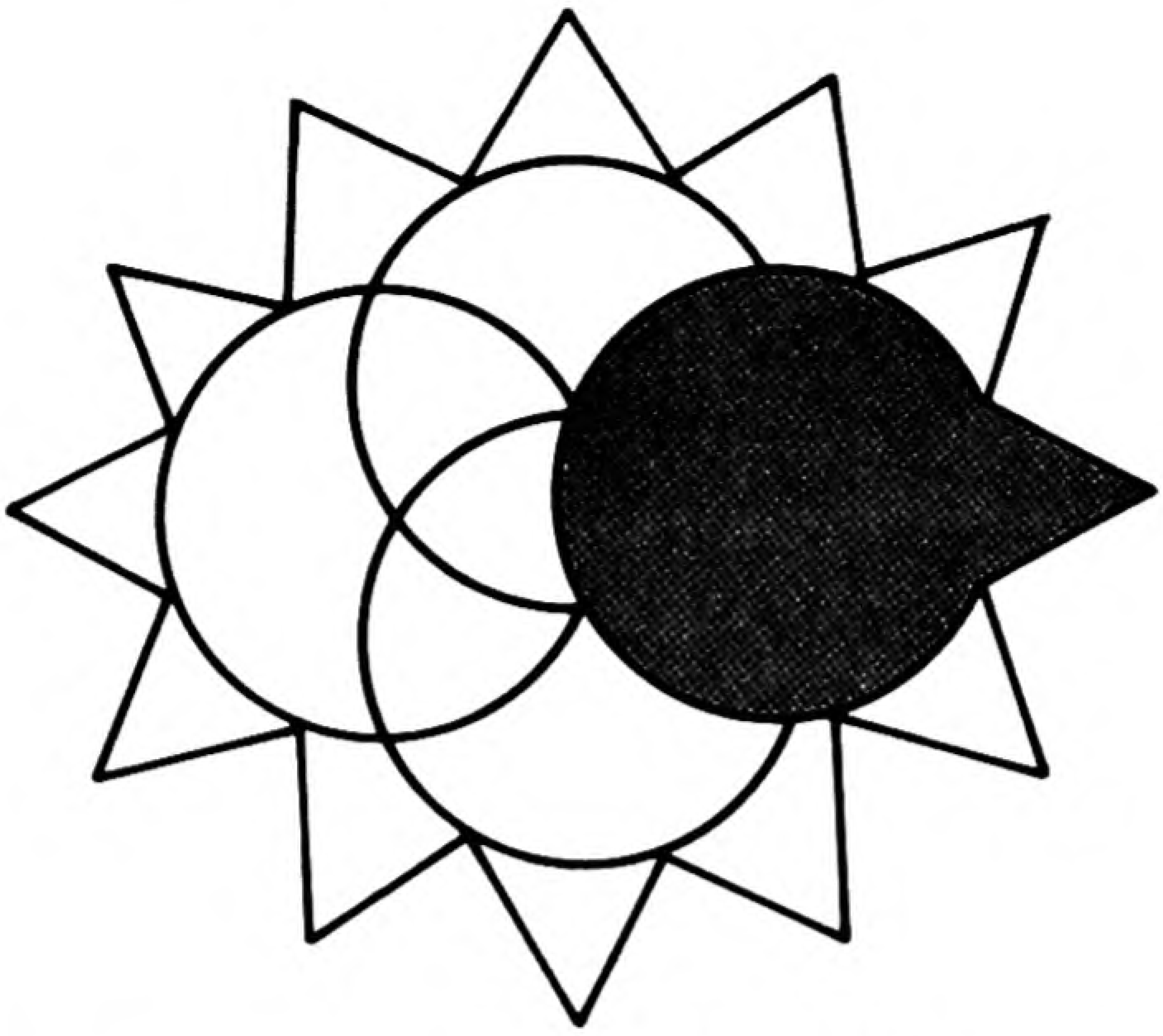
The initial effort required to develop a forecast from a leading indicator or some other cause of demand is considerable. Even after a causal forecast is accepted, it has to be watched constantly to see that the lead time and the proportions remain applicable. Causes of demand can change and the cause of the causes can change.

Just one abrupt deviation from normal may be all that is necessary to cause severe loss to a company. However, causal forecasting is more apt than historical forecasting to predict a turning point in demand, a point where growth switches to decay or the reverse. Even a hint of a turning point is vital information to a forecaster. Fortunes are made or lost from actions in anticipation of a shift in an existing trend.

### REFERENCES

1. *Webster's New World Dictionary,* The World Publishing Company, Cleveland, 1968.
2. From the English translation of Henri Fayol's *General and Industrial Management,* Pitman Publishing Corporation, New York, 1949.

# Chapter 6



# Scheduling

**KEY SUBJECTS**

A schedule is an ordered list of events or a time table of actions for accomplishing something. It must be specific because not only does it lay out individual assignments, but also it reveals the relationships of all assignments to each other and to the mission of the project.

*For network analysis a project is separated into activities, each based on particular undertakings and each defined by distinct beginning and end points.* An estimated duration is obtained for each activity and the sequence of performance for all activities is registered in a restriction list. This information can be displayed on an activity diagram, bar chart, or arrow network.

In an activity diagram, rectangles labeled to represent project activities are connected by arrows that establish the order in which the activities are to be done. The position and length of bars along a time scale in a bar chart reveal the sequence and duration of activities. Directed arrows represent activities in an arrow network. Which type of portrayal to use depends on the size of the project and the proposed use of the diagram.

*The critical-path method (CPM) and the program evaluation and review technique (PERT) were developed in the late 1950s. They won early and lasting fame as* *valuable management tools.* The main difference between the two is that PERT is designed for use in research and development work where activity durations are uncertain, while CPM is used for more familiar projects.

*Both CPM and PERT utilize arrow networks to describe a project and both employ the same calculation procedures, which can be done manually or by a computer.* Computations, based on information contained in the network, yield boundary times which set the earliest and latest start and finish times for each activity. Also given is the amount of leeway or slack available for scheduling activities, called *total float.* The critical path is the chain of activities with no float which stretches from the beginning to the end of the project.

*Many variations of network-scheduling are available for special applications.* The boundary times can be arranged to display an index of criticalness or to show resource commitments. Statistical measures in PERT can reveal the probability of meeting certain events. Computer-generated updating reports can aid continuous evaluation of ongoing projects. Extensions of CPM for cost analysis and project control are discussed in later chapters.

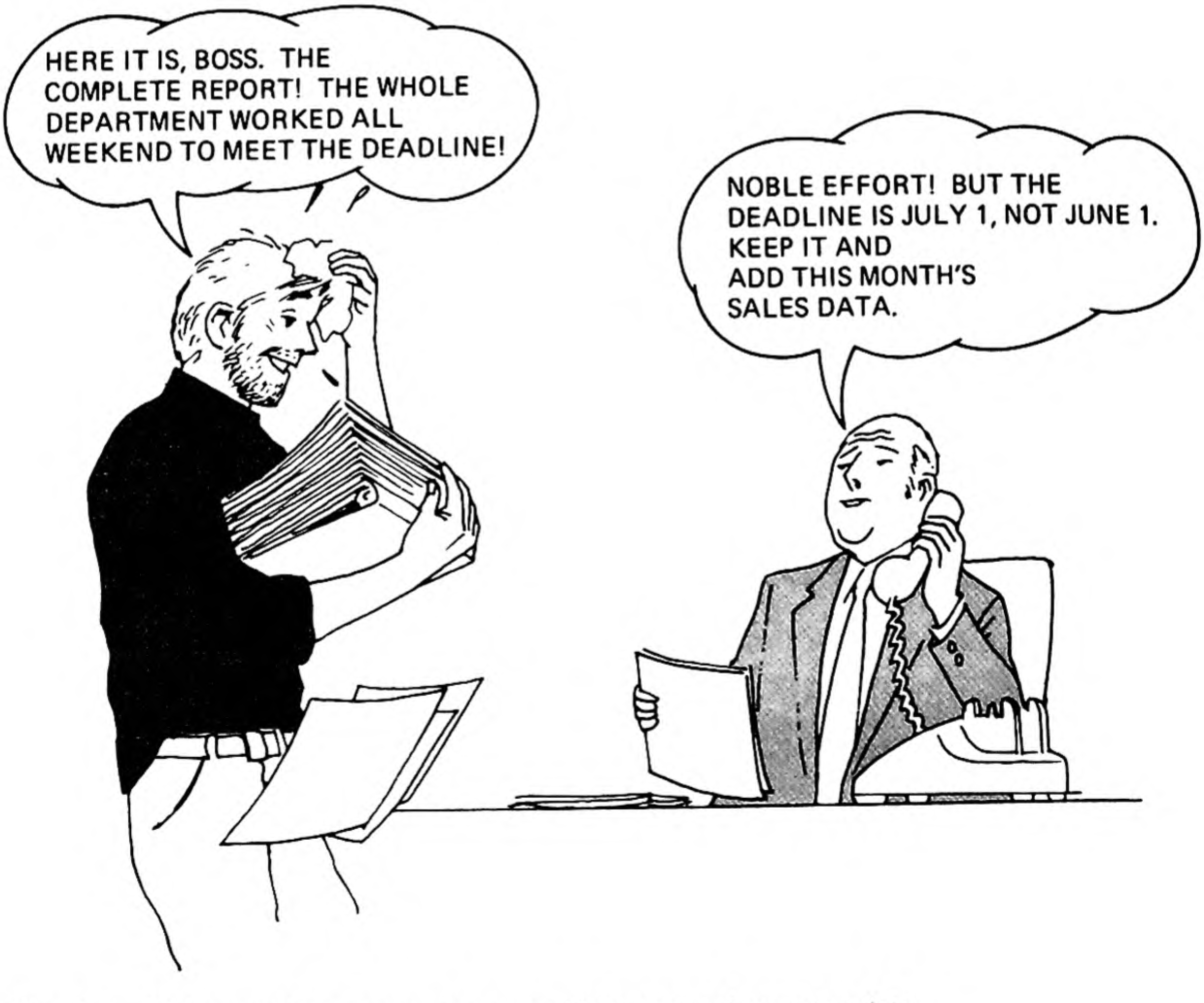

HERE IT IS, BOSS. THE COMPLETE REPORT! THE WHOLE DEPARTMENT WORKED ALL WEEKEND TO MEET THE DEADLINE!
NOBLE EFFORT! BUT THE DEADLINE IS JULY 1, NOT JUNE 1. KEEP IT AND ADD THIS MONTH'S SALES DATA.

*Fig. 6-1. Being on time means being neither too early nor too late.*

## WHEN?

As a result of planning, you end up with a list of things which have to be done. The list, of course, aims at things to be done in order to accomplish the goals which you set for the plan. Consider your progress toward a degree. The necessary subjects and their sequence have been established. Your college then sets up a schedule throughout the year so that all subjects which all students need are available in proper efficient sequence. Undoubtedly, you follow a daily, hourly schedule each term or semester. *When* something must be done is as important as *what* has to be done. Politics, business, commerce, and everyday life are rich with examples of good plans which were spoiled by poor timing. Figure 6-1 illustrates such a situation.

Small projects can usually be arranged mentally. A simple plan typically takes the form of a mental shopping list, such as you might use in purchasing the weekly groceries. For efficient shopping you mentally have to detail the frozen goods, the meat, the canned goods, the bread, etc., and the order in which they are arranged in the store to avoid back tracking. An ordered list works fine until it gets too long or the sequence of events gets too complicated. At that point, a more formal method of scheduling is needed.

In the middle 1950s a new method of scheduling known as *network analysis* came into existence. Few, if any, new management tools have received such wide acclaim and acceptance so soon. The key feature of this new tool was the use of a network of connected lines drawn to represent the different jobs required to complete a project. In order to construct a network a scheduler has to define each job and to visualize how it relates to all other jobs. The completed network gives a visual display of the project that permits better communication and review. The network format also allows computerized computations for time schedules of large projects and for resource analyses.

In the following sections the basic concepts of scheduling are discussed first. Next we look at a rather easy method of activity diagraming. Then we explore basic network-scheduling methods. Extensions of these methods are examined further in later chapters.

## SCHEDULING CONCEPTS

The first task we must face in scheduling is the need to be specific. A schedule is a message or outline that not only spells out individual assignments, but also reveals how all these assignments are connected, and how they rely on each other in fulfilling the project. It is a way of thinking, a realization that a plan must be thoroughly thought out before it can be communicated clearly.

### Activity Designations

One of the toughest tasks in scheduling is to break down a project into its component activities. There are few rules to guide this process of breaking down. You certainly need to be very familiar with the project or have experienced help on whom you can rely.

An early step is to peg the beginning and end points of the total project. This sounds easy but can be tricky. For instance, suppose that the project is to paint a room. When does the project begin? Does it begin when the paint is selected, when an order is placed for painting supplies, when the paint brush first touches a surface, or when? Likewise, how do you tell when the job is finished? After all the paint is on? After it dries? After clean-up? After passing inspection? A good scheduler must identify the distinct acts which mark the boundaries of the project.

Not only must the project have a distinct beginning and ending, but also all activities throughout the project must have distinct beginning and end events. The room-painting project mentioned above might be just part of the renovation of an entire office building. The following considerations might influence the activity divisions:

1. Work done by each agency, subcontractor, or department should be separated into individual activities.
2. Improvement of administrative control comes from activity breakdowns that recognize special crafts, such as salesmen, carpenters, department heads, plumbers, police, engineers, etc.
3. Structural elements such as digging a foundation, laying floors, or constructing walls are natural activity divisions.
4. When a certain resource is limited as it might be with one-of-a-kind machines or a special craftsman, work requiring that resource should be separated from the other activities.

The object of activity designation is to separate the entire project into easily distinguishable steps, each one based on separate tasks with measurable outcomes.

### Activity Times

The importance of well-defined activities becomes very apparent when we have to estimate the length of time required for each one. Referring again to the paint-room project, it is obvious that the time required to complete the painting depends on which events are used to define its start and its finish. Once the scheduler has set these boundaries, he can make the time estimates himself or if he needs to, go to other sources to obtain expected times. In many cases, the most appropriate source is the person who will carry out the activity.

Time allocations for completing an activity are generally based on expectations of normal working conditions and the usual standards of performance. If, however, it can be anticipated in advance that unusual obstacles will have to be overcome, estimated times should reflect the situation. For example, if construction work has to be done outdoors in a northern locality, more time would be allowed to complete the activity during the winter than during the summer. Similarly more time would be scheduled when shortages of experienced workers occur, when hazardous weather conditions develop, or when unfamiliar project requirements are forecast.

### Activity Restrictions

Another phase of scheduling is determining the sequence in which activities are to be done. Sequencing is usually easier than setting activity descriptions or estimating times. We tend to naturally think of activities in a more or less logical order of occurrence. Therefore, as each activity is considered, its location relative to other activities in the project can be set by determining what activities must precede it and which must follow it. Some schedulers prefer to work backwards from the end event because they feel it is easier to think of work which must precede an activity than to think of work that follows it. Others prefer to build from the first event, listing in order each following or postrequisite activity. Either way is acceptable as long as it results in the final production of accurate sequencing.

Even a small project will involve most of the considerations which go into scheduling. Consider a situation in which city officials plan to conduct a community attitude survey. Most communities, these days, are interested in urban renewal. Let us suppose that the city officials wish to know what public opinion is about some industrial and commercial development involved in an urban renewal project. Those in charge of the project have decided that it will start with the approval of the survey and will end with the analysis and distribution of the results. Between the beginning and end events a huge number of activities could be inserted if a finely detailed schedule were needed. In order to avoid becoming bogged down with minute details, most schedulers first make a skeleton activity list, which includes only major functions. After putting this skeletal list in order of occurrence, schedulers can subdivide activities to whatever level of detail they may need.

Figure 6-2 is a worksheet for the attitude survey project. Each activity is described by a short phrase, usually a verb and a noun. Symbols are assigned to activities to reduce writing time for later notations, such as the postrequisite listing. A postrequisite activity is one that can begin immediately after but not before the preceding activity is completed. A shorthand notation, $A < B$, is read "A precedes B" or "B is a postrequisite of A." A comment column is used in the illustration to record the events that bracket each activity. Comments could also include responsibility or crew assignments and required resources.

## ACTIVITY DIAGRAMS

Although the listing given in Figure 6-2 is a complete description of the survey project, it can be put in a more useful form. There are many ways to display schedules, ranging from computer printouts to colorful boards on which magnetized clips, displayed in an appropriate pattern, represent activities. The most

| ACTIVITY DESCRIPTION | ESTIMATED TIME | ACTIVITY SYMBOL | | POST-REQUISITE | COMMENTS |
|---|---|---|---|---|---|
| Approve survey | 10 | A | < | B, C, D | (B)- Council meeting (Ju[illegible] 1)<br>(E)- Signed approval |
| Hire canvassers | 5 | B | < | E | (B)- Advertise for work<br>(E)- Select personnel |
| Design questionnaire | 8 | C | < | E, F, G | (B)- Hire public relations firm<br>(E)- Questionnaire approved |
| Select households | 3 | D | < | H | (B)- Get city directory<br>(E)- Selected addresses listed |
| Train canvassers | 5 | E | < | H | (B)- Training plan received from public relations firm<br>(E)- Training completed |
| Publicize survey | 4 | F | < | H | (B)- Contact newspapers<br>(E)- Notices printed |
| Print questionnaire | 3 | G | < | H | (B)- Deliver form to printer<br>(E)- Receive all copies |
| Conduct survey | 7 | H | < | I | (B)- Start canvassers on routes<br>(E)- Completed questionnaires |
| Analyze results | 12 | I | | | (B)- Questionnaires to analysts<br>(E)- Receive analysis report |

*Fig. 6-2 Worksheet for activities involved in an attitude-survey project. All estimated times are in units of 8-hour workdays. The restriction list uses letters to represent activities and the symbol of < which stands for "precedes" (A < B,C,D is read "activity A precedes activities B, C, and D"). To better define each activity, the beginning event (B) and the end event (E) are described in the comment column. All activities could be subdivided to allow more detailed descriptions. For example, the activity "Analyze results" could include the subactivities of "Form analysis team," "Tabulate data," "Apply statistical tests," "Interpret test results," "Write preliminary report," "Review report," "Write final report," "Approve report," "Submit report." The appropriate degree of detail depends on the intended use of the network.*

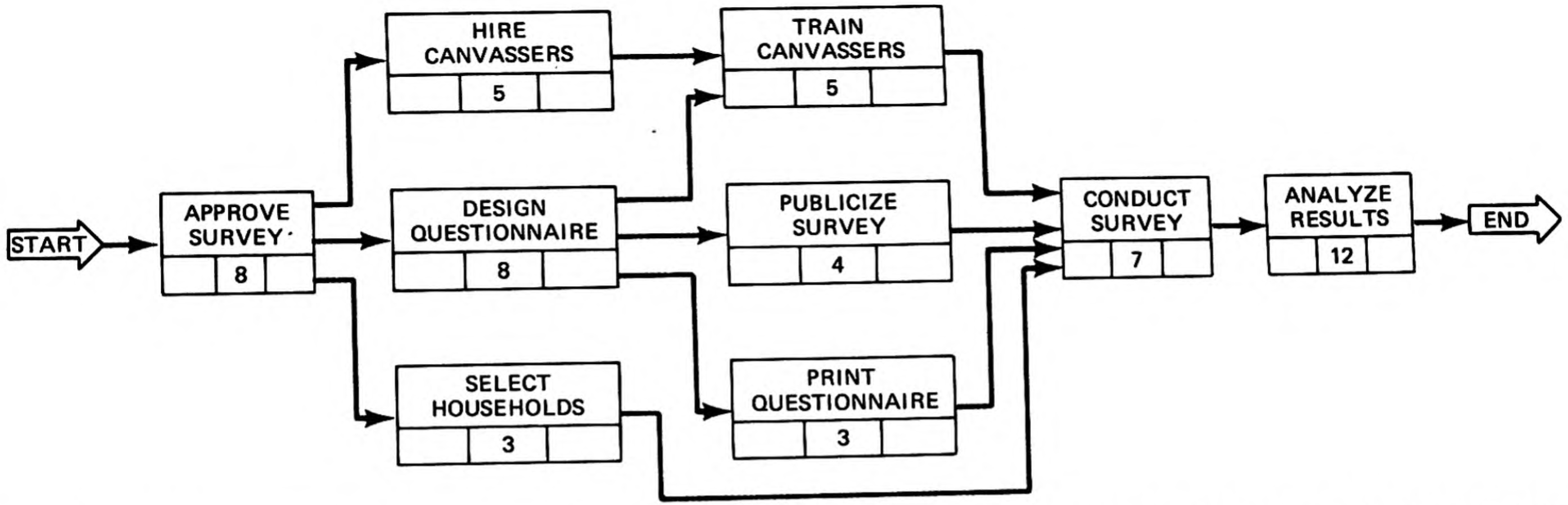

START
APPROVE SURVEY
8
HIRE CANVASSERS
5
DESIGN QUESTIONNAIRE
8
SELECT HOUSEHOLDS
3
TRAIN CANVASSERS
5
PUBLICIZE SURVEY
4
PRINT QUESTIONNAIRE
3
CONDUCT SURVEY
7
ANALYZE RESULTS
12
END

*Fig. 6-3. Activity diagram for a public opinion survey. Rectangles are labeled with activity descriptions and estimated durations. Arrows link the rectangles to establish a sequential relationship of activities.*

used display format during the planning and evaluation phase of a project is a hand-drawn network. Later on, computerized or mechanical bar charts are more useful during the control phase of a project because data can be handled more completely and quickly by mechanical means. Each activity can be monitored to see how closely it conforms to the plan.

Not all networks drawn for project management look alike, but all are graphical representations of a project plan showing the interrelationships of activities. In this chapter several variations are discussed. Which version the planner uses depends on personal preference and suitability for each occasion.

### Activity-on-Node Diagraming

An activity diagram as shown in Figure 6-3 is probably the easiest to draw. Each activity is represented by a node or centering point labeled with an activity description and its duration.This general format is logically known as an *activity-on-node network*. In the given version, each node is a rectangle divided into segments. The way the rectangle is divided depends on the function of the network. Space can be provided to show resource allocations, scheduling leeway, or other information.

Arrows connect the rectangles to establish an order of accomplishment. Time flows in the direction of the arrowhead. Thus an arrow pointing from rectangle A to rectangle B always means that activity A must be completed before activity B can begin. Placement of the arrows follows the order established in the restriction list given in Figure 6-2.

Construction of an activity diagram begins with arrows drawn from the "start" event to the left side of all activities which must follow (postrequisites). For the survey example, activity A is the only one without a preceding activity. The left side of an activity rectangle represents the start of the activity, and the right side represents its completion. After the "start" event, every activity in the project has at least one arrow on each side of its rectangle. The final arrow goes from activity I, which has no postrequisites, to the "end" event. Therefore, completion of activity I is the last event in the project. After all the labeled rectangles have been linked by arrowed lines, the content and order of tasks needed to meet the project objectives are recorded.

Once a scheduler becomes familiar with networks, he can often skip the worksheet phase and go directly to an activity diagram. A preprinted page covered with rectangles may be used to record the activity breakdowns. Time durations for the activities are entered as they are estimated. The sequencing is done by

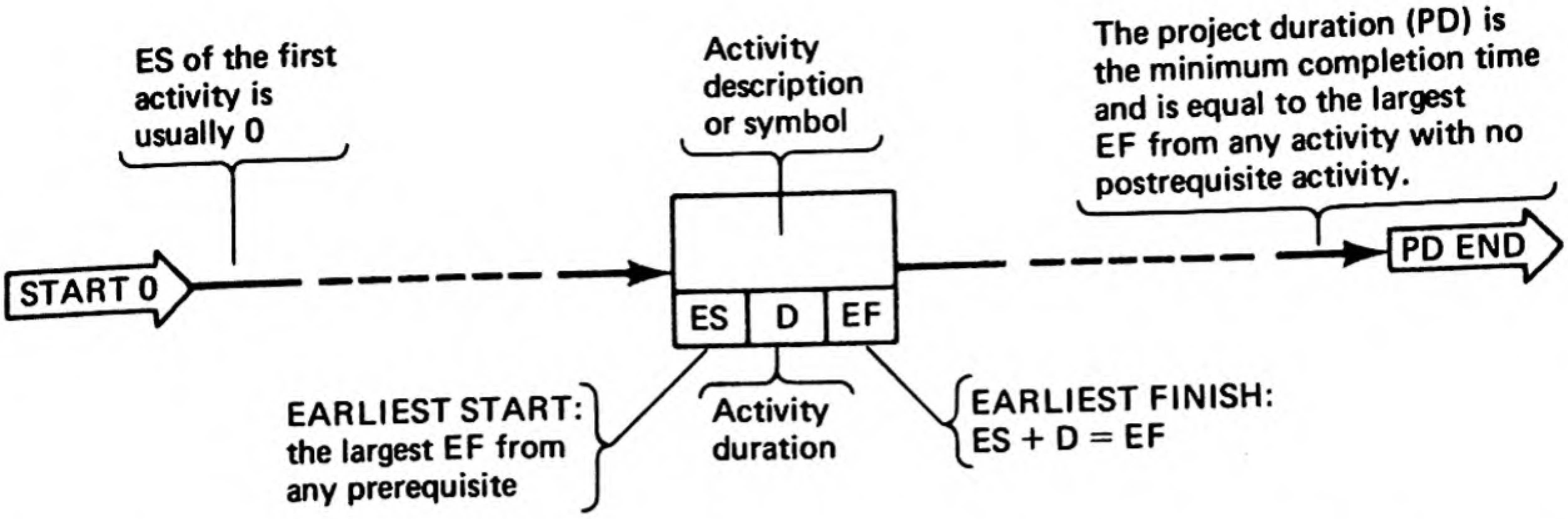

ES of the first activity is usually 0
Activity description or symbol
The project duration (PD) is the minimum completion time and is equal to the largest EF from any activity with no postrequisite activity.
START 0
PD END
ES
D
EF
EARLIEST START: the largest EF from any prerequisite
Activity duration
EARLIEST FINISH: ES + D = EF

*Fig. 6-4. Conventions and procedures for calculating the earliest and latest start times in an activity diagram.*

drawing appropriate arrows. Because the activity descriptions are seldom entered on the printed form in their eventual order of accomplishment, arrows might criss-cross or run from right to left. The resulting confusion is not serious unless it leads to inaccurate interpretation since network construction is just an intermediate stage in producing a refined schedule.

### Earliest Start Scheduling

More information about a project is revealed by calculating its total duration and the earliest time each component activity can begin. Activity rectangles provide space for time calculations. In Figure 6-4 the box at the lower left is for the earliest possible start (ES) that would not interfere with the time needed to complete all prerequisite activities. The first activity in a project is usually given a start time of zero, although any number could be used because all starts after that add up from the initial figure. The middle box is the activity duration (D). The earliest finish time (EF) entered in the box on the right is the sum of the other two boxes: $ES + D = EF$.

The earliest start for any activity with prerequisites is the largest earliest finish among the prerequisites. For example, the slowest sheep to jump the fence (if they all must go over one at a time) will hold up the entire flock. Or, the plasterers cannot begin plastering rooms until the plumbers have finished installing pipes in the walls. Or, if three plumbers working on one project take 7, 9, and 12 hours respectively to complete their assignments, the earliest that the plasterers could begin would be 12 hours after the plumbers started. By similar reasoning it is evident that the earliest time the project can be complete (PD) is equal to the largest early finish of any activity.

The survey project is again shown in Figure 6-5, this time with the start and finish boundary times entered in the activity rectangles and with the activities repre-

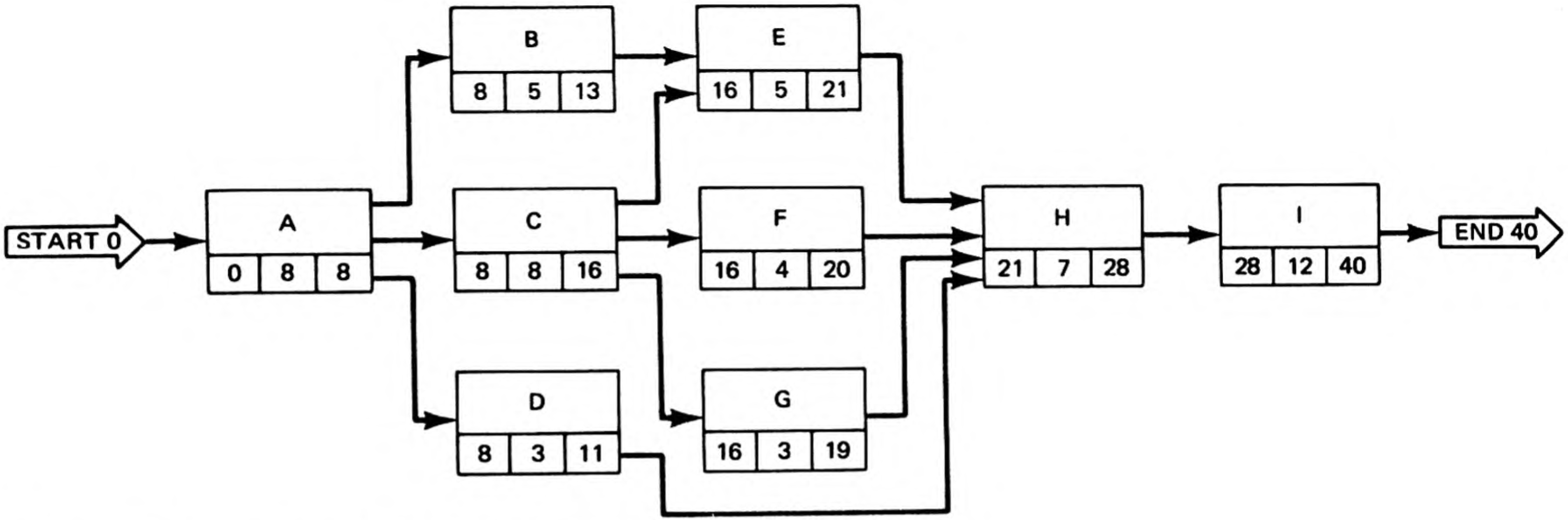

START 0
A
0
8
8
B
8
5
13
C
8
8
16
D
8
3
11
E
16
5
21
F
16
4
20
G
16
3
19
H
21
7
28
I
28
12
40
END 40

*Fig. 6-5.* *Earliest start and finish times for the activities in the survey project.*

sented by letter symbols. The sources of the boundary times are revealed in the following tabulation of calculations:

1. The project is assigned a start time of 0.
2. Zero is entered as the ES of A; EF of A = 0 + 8 = 8.
3. Eight is entered as the ES for activities B, C, and D; EF's are obtained by adding respective durations to 8: 13, 16, and 11.
4. ES for Activity E is the larger EF from its prerequisites B and C; thus 16 (EF of C) is added to the duration of E to get $EF_E = 16 + 5 = 21$.
5. Sixteen is the earliest start for F and G. Adding activity durations to 16 gives $EF_F = 16 + 4 = 20$ and $EF_G = 16 + 3 = 19$.
6. Activity H has four prerequisites. It cannot be started until all are completed. The longest elapsed time from the start is the path A–C–E which has an earliest finish of 21. Therefore, $ES_H = 21$ and $EF_H = 21 + 7 = 28$.
7. The last activity, I, has an ES of 28 and $EF_I = 28 + 12 = 40$. Thus the project duration for the survey is 40 days.

Activity diagrams are even more versatile than already demonstrated. Special situations, such as a condition that two activities must start at the same time, can be shown by an arrow connecting the left side of both activities. Additional time calculations of the type described in this chapter's section on critical path scheduling can be incorporated into the diagram. The person expected to do the work can be noted on the activity rectangles. Beginning or end event descriptions can be inscribed on the arrows. However, such additions tend to clutter the network and reduce its value as a communication tool. It is therefore advisable to convert the developed schedule to a bar chart in order to avoid misinterpretation of assignments.

## BAR CHARTS

Henry L. Gantt is credited with introducing bar charts to represent work assignments and objectives. Over more than half a century, many adaptations have been made to Gantt's original charting techniques. Network scheduling came about partly because of efforts made to overcome certain deficiencies in bar charting.

A bar chart of the survey project based on the activity diagram is shown in Figure 6-6. Note the clarity of the schedule. The earliest starts and finishes are cleanly indicated and the calendar dates specify precisely when the work is to be accomplished. The bar chart is better suited, however, to project control and supervision (discussed in Chapter 11) than to project planning and schedu-

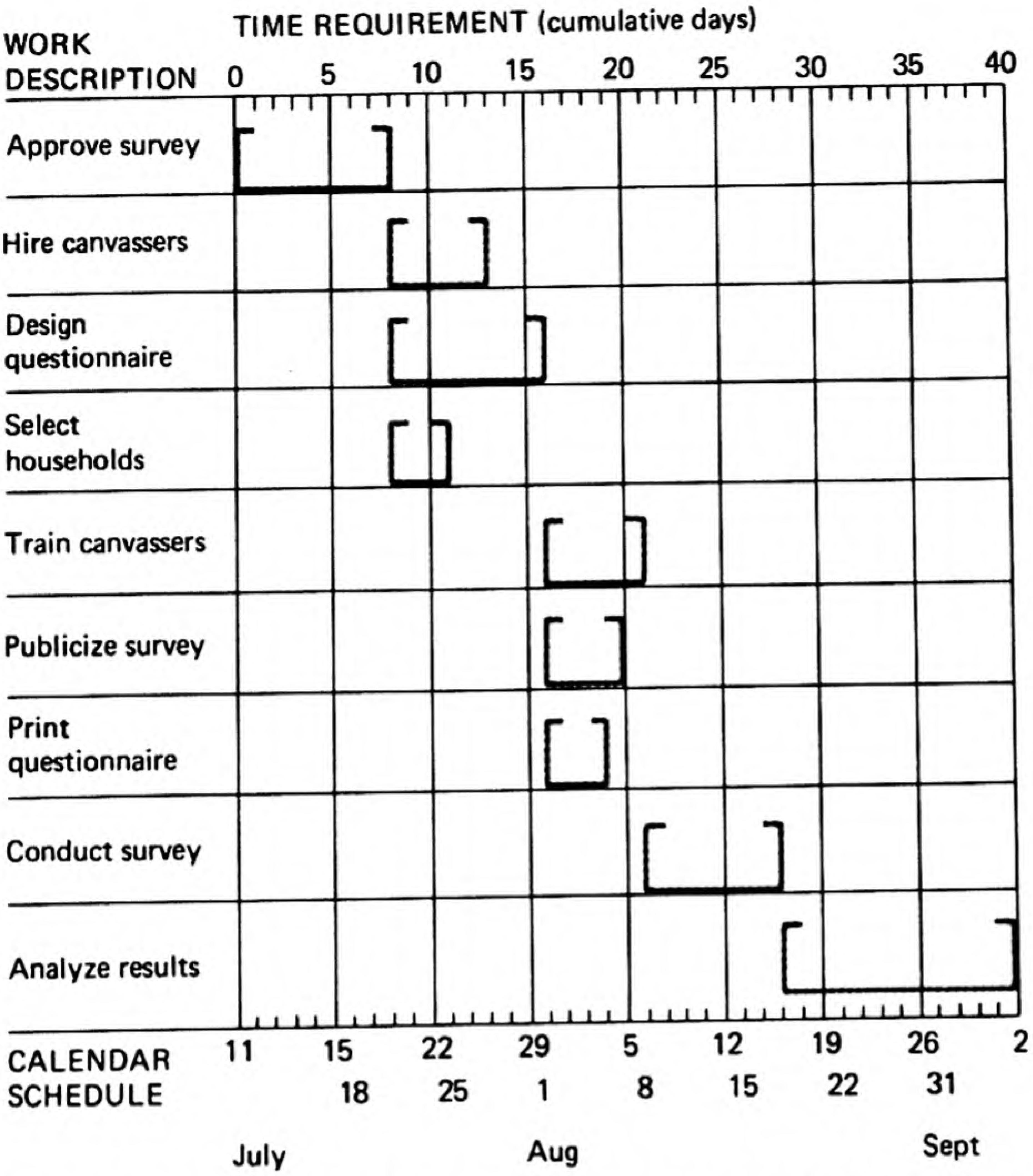


*Fig. 6-6. Bar chart for the survey project. Bars are positioned in the chart to represent activity durations beginning at their earliest start times. When the chart is used to monitor progress, the bars are colored or blocked in to show the current state of completion.*

ling. Listed below are some of the disadvantages of bar charts which are largely overcome by network scheduling techniques.

1. Planning and scheduling have to be decided at the same time in order to draw an appropriate bar. Attempting to sequence and assign times simultaneously is very difficult in a complex project.
2. Interrelationships of activities are not shown on a bar chart. Prerequisite relationships are implied but not defined explicitly. Which activity must come first is particularly important when different activity arrangements are being studied in the planning phase.
3. Construction of bar charts for planning very large projects, say 1,000 or more activities, is almost impossible due to the size of the chart necessary to picture everything. Networks, especially arrow networks described in the next section, offer a far more compact format which displays more information useful for management analysis.

## CRITICAL-PATH METHOD

In 1956 the DuPont Company undertook a study to determine how computers might be used to improve planning, scheduling, and progress reporting. What emerged from the study is the now famous *critical-path method* (CPM). This method not only utilizes the data manipulating dexterity of the computer, but also forms the backbone of a body of management procedures for analysis and control applicable to almost any type of endeavor. The early fame of CPM came from its use in the construction industry. Now it is applied in such diverse programs as:

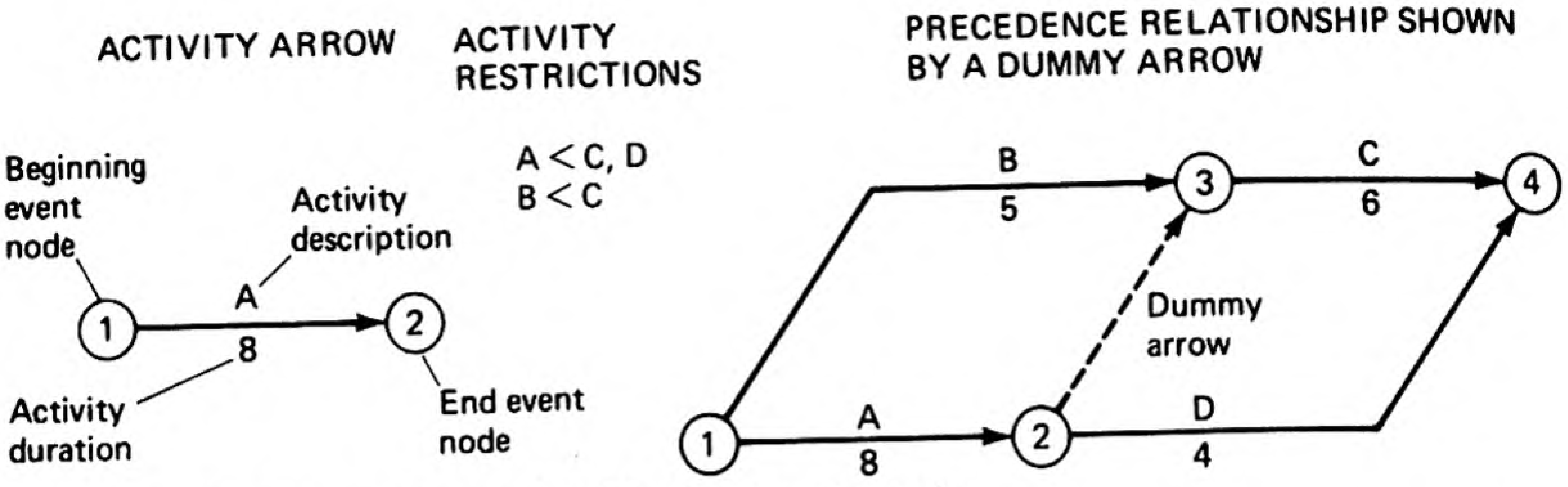
- Factory maintenance scheduling
- Planning political campaigns
- Installing and debugging computer systems
- Launching new products and rockets
- Producing plays and motion pictures
- Remodeling or making additions to production facilities
- End-of-month closing or accounting records
- Manufacturing and assembly of custom products

All the programs mentioned share two characteristics suitable for CPM:

1. They have well defined activities which, when completed, achieve the objectives desired.
2. Enough information is known about the activities in the project to assign definite resource allocations, specify durations, and establish a sequence of operations.

### Activity-on-Arrow Networks

The critical-path method employs a network composed of arrows that represent activities, called *activity-on-arrow* or, more simply, arrow networks. The same activity information required for an activity diagram is also required for an arrow network. In fact, all the time calculations and analysis techniques used in CPM can be shown by activity diagrams. Tradition is probably the reason arrow networks are more widely used than other network formats. The first CPM applications used arrow networks. Some users also feel that arrow networks are more visually descriptive of the work flow in a project. The authors suggest that activity diagrams are better suited to smaller projects relying on hand computations of activity boundary times, while arrow networks are more appropriate for larger, computerized applications and those including cost or resource analyses.


ACTIVITY ARROW

ACTIVITY RESTRICTIONS

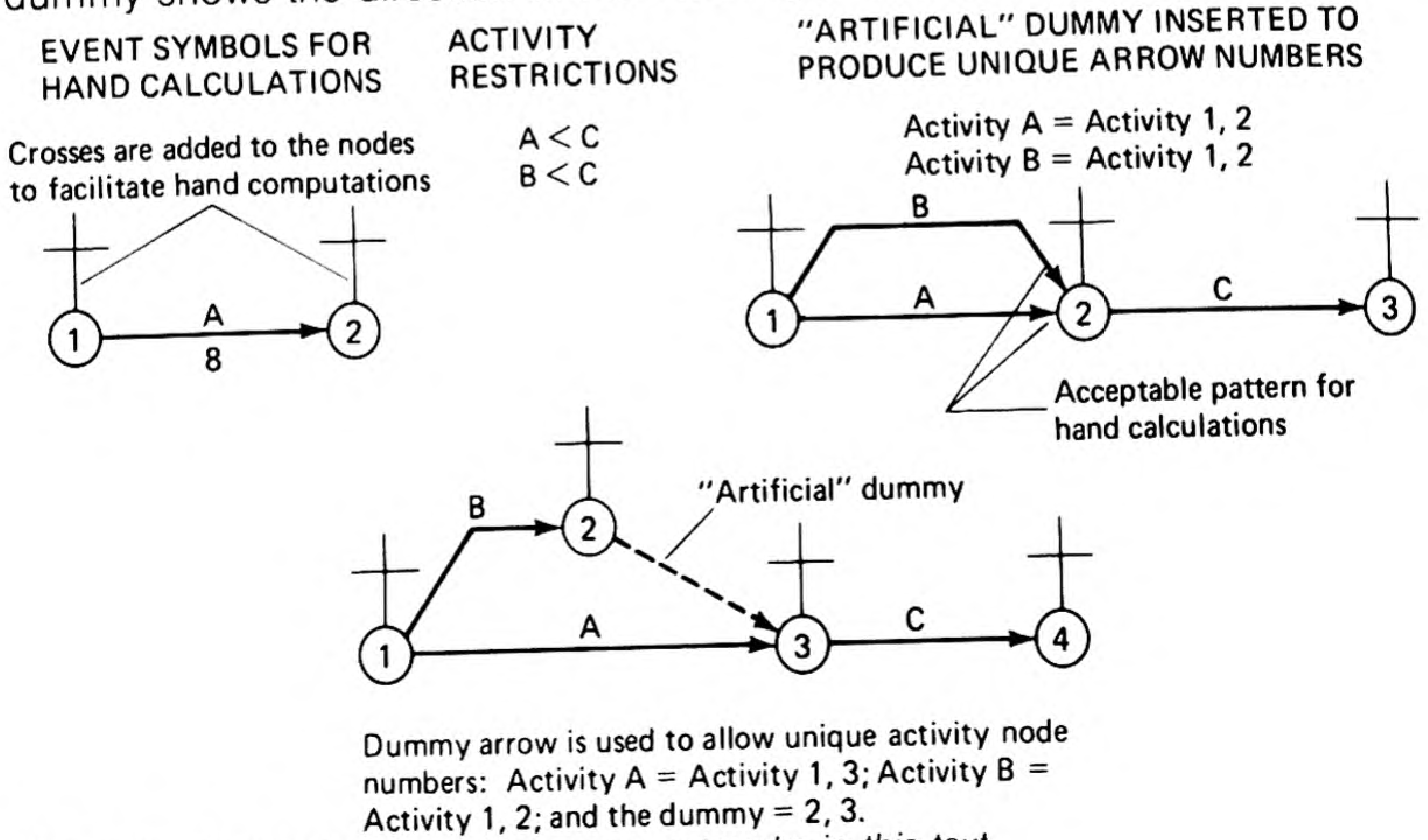
PRECEDENCE RELATIONSHIP SHOWN BY A DUMMY ARROW

Beginning event node
Activity description
A
8
1
2
Activity duration
End event node
A < C, D
B < C
B
5
C
6
3
4
Dummy arrow
A
8
D
4
1
2

*Fig. 6-7. Basic symbols used in CPM arrow networks.*

Basis symbols used in arrow networks are given in Figure 6-7. The activity description or a letter symbol is written above the activity arrow. An arrow can be drawn at any angle and with any length because arrow networks are not drawn to a time scale; the duration fo the activity is noted by a number below the arrow. The circle nodes at both ends of the activity arrow represent the beginning and end events of the activity. The numbers in the circles identify the activity for computer programs; activity A would be known as activity 1,2. Note that the end node of an activity is the beginning node of the next one.

A dummy is a dashed arrow used to show a precedence relationship among activities. A "logic" dummy is needed when two or more activities share a common postrequisite but at least one of the activities also has a unique postrequisite. In Figure 6-7 activity A has the same postrequisite (C) as does Activity B, but it also has a unique postrequisite in activity D. The dummy shows that event 2 must be completed before event 3 can begin or, equivalently, that activity A must be completed before activity C is begun. The arrowhead on the dummy shows the direction of the one-way restriction.


EVENT SYMBOLS FOR HAND CALCULATIONS

ACTIVITY RESTRICTIONS

"ARTIFICIAL" DUMMY INSERTED TO PRODUCE UNIQUE ARROW NUMBERS

Crosses are added to the nodes to facilitate hand computations
A
8
1
2
A < C
B < C
Activity A = Activity 1, 2
Activity B = Activity 1, 2
B
A
C
1
2
3
Acceptable pattern for hand calculations
"Artificial" dummy
B
A
C
1
2
3
4

Dummy arrow is used to allow unique activity node numbers: Activity A = Activity 1, 3; Activity B = Activity 1, 2; and the dummy = 2, 3.

*Fig. 6-8. Conventions used for arrow networks in this text.*

Another use of dummy arrows is displayed in Figure 6-8. Since some computer programs for CPM calculations require each activity to have a unique pair of nodal numbers, a problem occurs when two or more activities have the same postrequisite. As shown in the top network of Figure 6-8, both activities A and B have the same node numbers because both begin and end with the same circles. This condition is acceptable for hand calculations, but a dummy should be inserted to form unique activity numbering for computer applications. In the lower network, a dummy (2,3) has been inserted between activities B and C. This "artificial" dummy maintains the same restrictions but forces unique numbering for A and B; A becomes activity 1,3 and B becomes activity 1,2 for computer coding. All the CPM networks in this text will use "artificial" dummies, even when calculations are to be performed manually. The event crosses illustrated in Figure 6-8, however, will be added to the nodes only when hand calculations are shown.

The survey project diagramed in Figures 6-3 and 6-4 is represented as an arrow network in Figure 6-9. Event 1 marks the beginning of the project and event 7 the end. All projects should begin and end with a single event. Two dummies are used in the network. The dashed arrow from event 3 to event 4 indicates that activity C must be completed before activity E can begin. Dummy 5,6 is necessary to avoid having the same activity nodal numbers for both activities F and G. It would make no difference if activity F instead of G was attached to the artificial dummy.

Most beginners have difficulty in drawing arrow networks. With practice it becomes easier because you begin to recognize network patterns while you scan your restriction list. It usually helps to start by connecting as many activities as possible that have a single postrequisite. Networks are easier to check

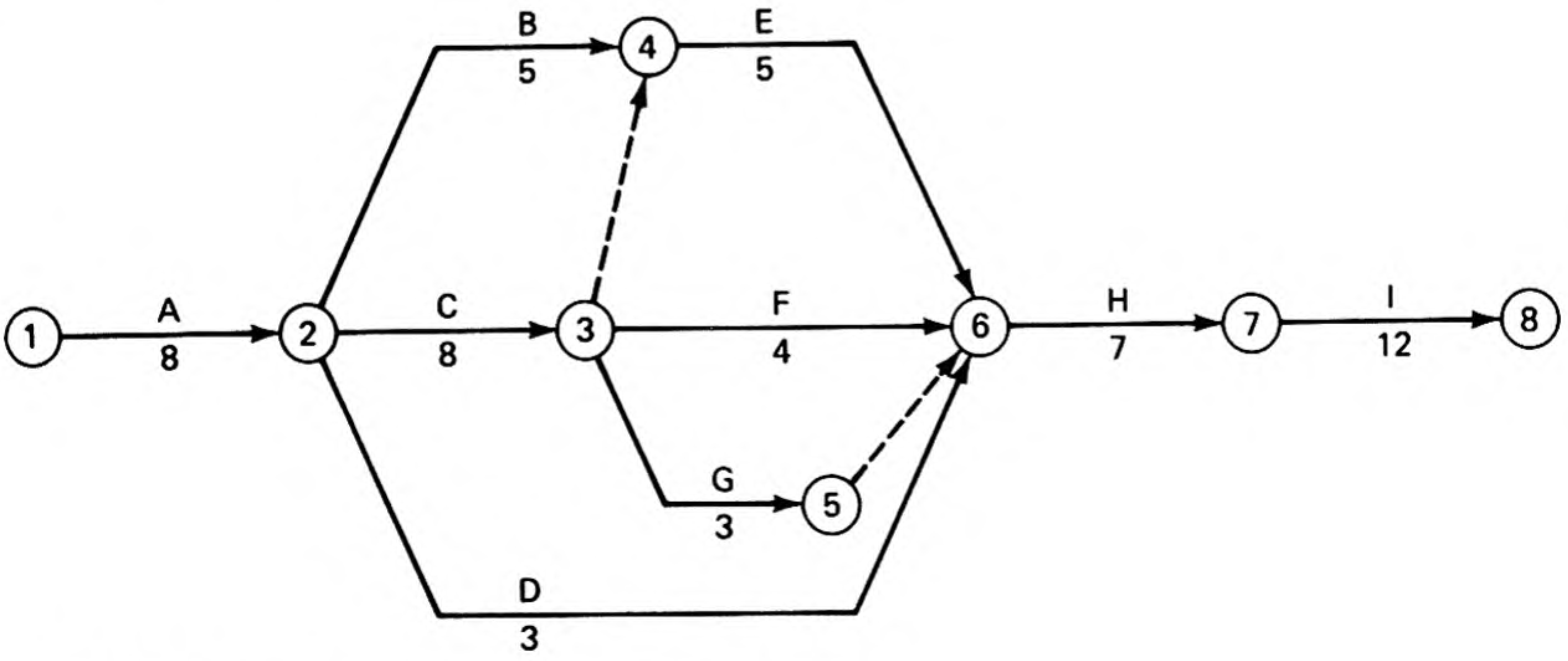


*Fig. 6-9. Arrow network for the survey project.*

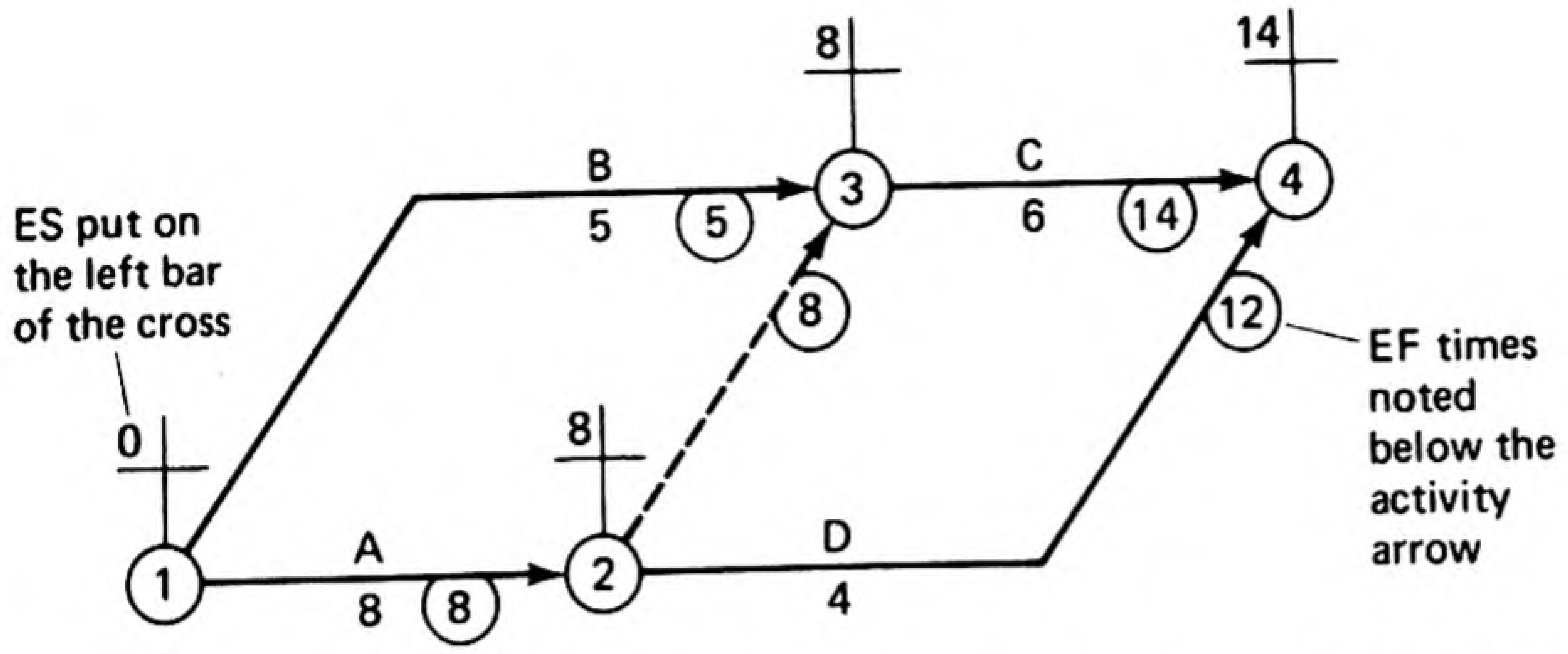

ES put on the left bar of the cross
0
8
8
14
B
5
5
3
C
6
14
4
8
12
EF times noted below the activity arrow
1
A
8
8
2
D
4

*Fig. 6-10. Conventions for calculating earliest start and finish times.*

if crossovers are minimized and all arrows run from left to right. It is often convenient first to sketch complex sections of a network on a blackboard, where erasures are easy, and then to transfer the pattern to paper.

### Boundary Time Calculations

An activity is described by five boundary times:

- Earliest start (ES)—earliest possible starting time which allows time for all prerequisite activities to be completed.
- Earliest finish (EF)—equals the activity's ES plus its duration.
- Latest start (LS)—latest possible time an activity can be started to avoid delaying the minimum project-completion time.
- Latest finish (LF)—equals the activity's LS plus its duration.
- Total float (TF)—the amount of slack or scheduling leeway available between the time an activity can start and when it must start: $TF = LS - ES = LF - EF$.

We have already described and illustrated the procedure for calculating earliest start and finish times in activity diagrams. The same applies for CPM arrow networks. Times are entered in the network as shown in Figure 6-10. ES values are placed on the left bar of the cross at each node. The value entered is the largest EF of all activities merging at a node. EF times may be noted as shown below the terminal end of an arrow or they can be recognized mentally. Observe that the dummy is treated like an activity with a zero duration. The process of calculating earliest boundary times is known as a *forward pass* through the network.

Latest start and finish times are calculated by a *backward pass* through the network. Calculations begin with the last event in the network which is assigned a latest finish equal to the largest EF of any activity in the project, the PD. The latest start for all activities terminating at the last event are computed by sub-

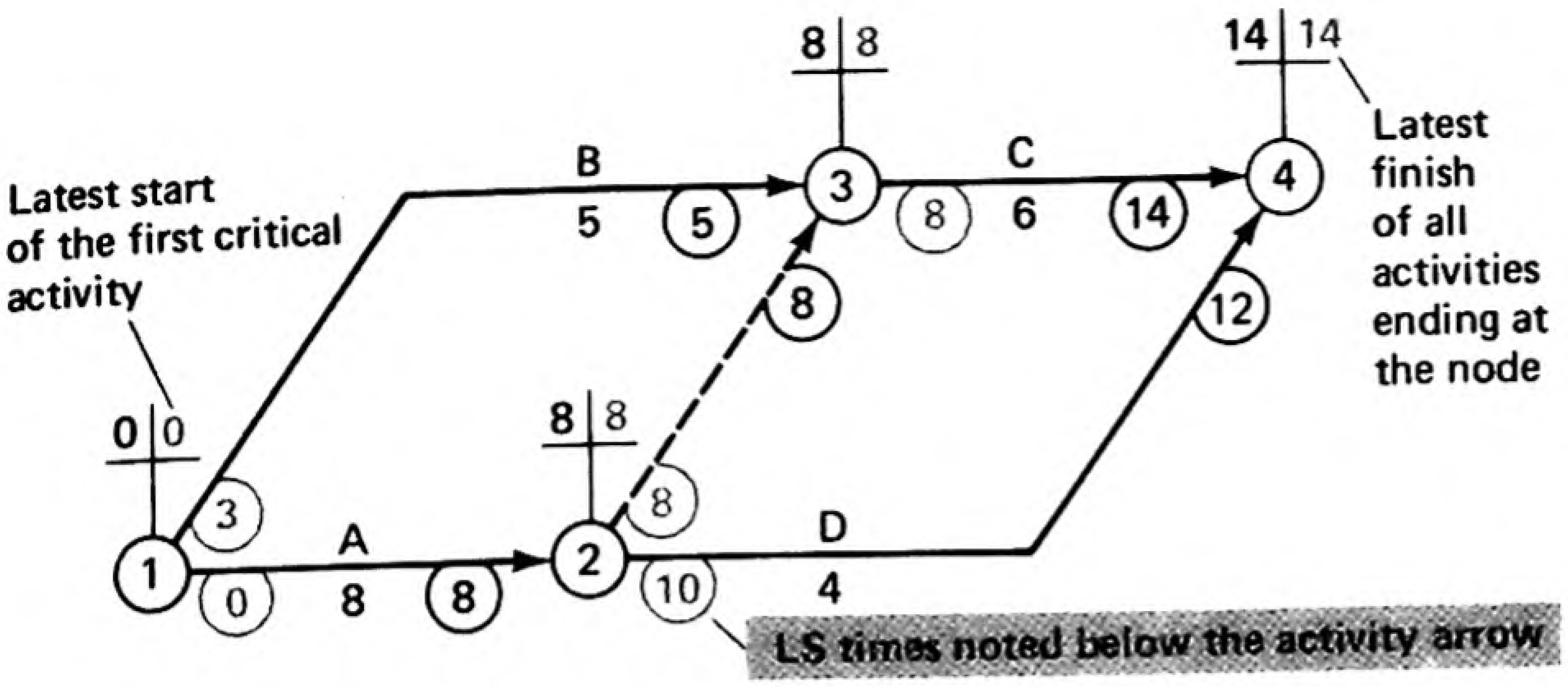

8 | 8
14 | 14
Latest finish of all activities ending at the node
Latest start of the first critical activity
0 | 0
8 | 8
B
5
C
6
A
8
D
4
1
2
3
4
3
0
8
5
8
8
14
12
8
10
LS times noted below the activity arrow

*Fig. 6-11. Conventions for calculating latest start and finish times.*

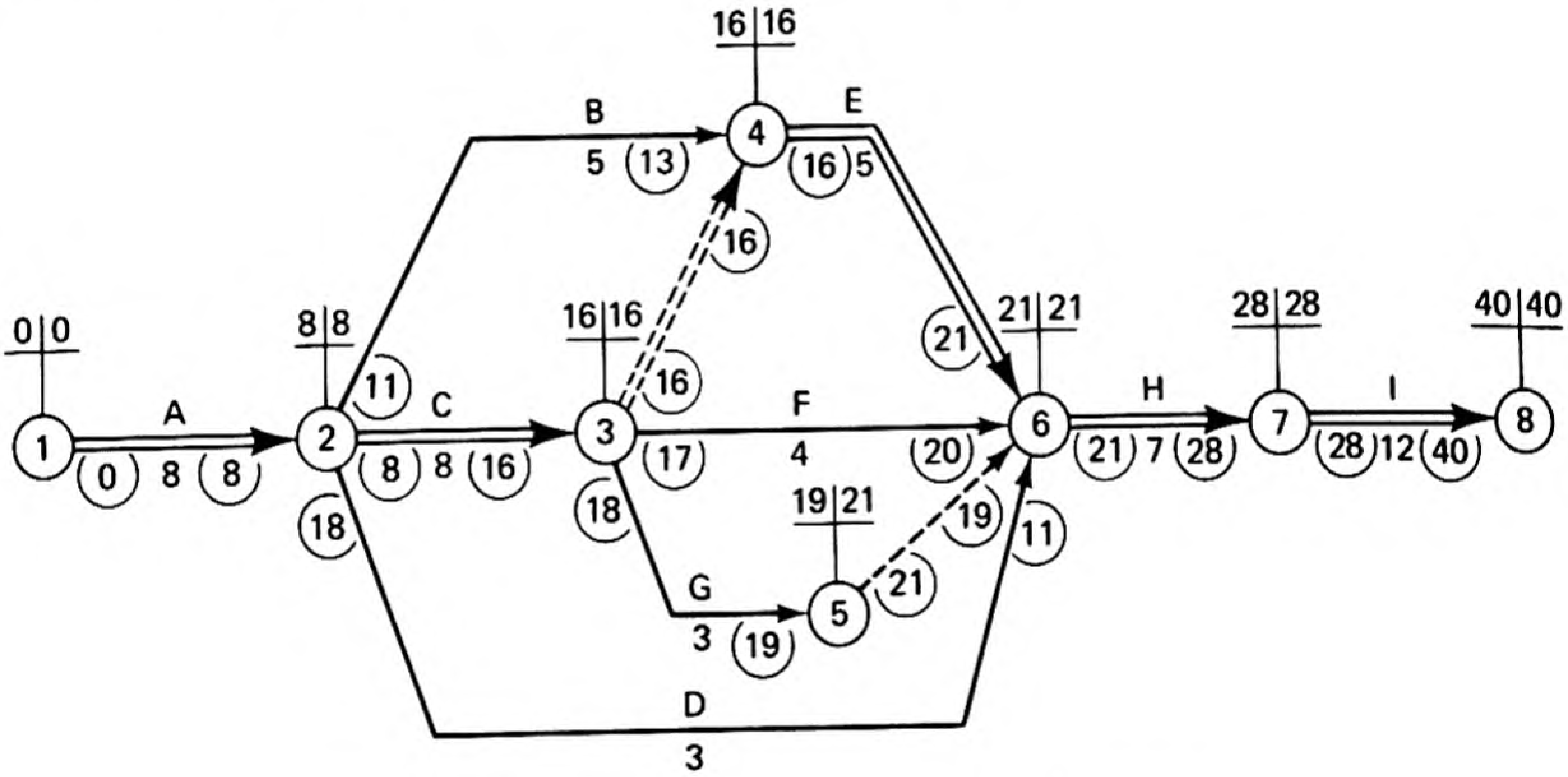
tracting each activity's duration from PD. Then the smallest LS of any activity leading from an event is entered on the right bar of that event's cross. This value then becomes the latest finish for the next round of calculations. The procedure is described below with reference to Figure 6-11.

1. The largest EF from the forward pass is entered on both bars of the last cross, node 4. This is the minimum project duration, $PD = 14$.
2. Latest starts for C and D, calculated as $LS_C = 14 - 6 = 8$ and $LS_D = 14 - 4 = 10$, are entered near the origin of their respective activity arrows.
3. At node 3, the LS of C is entered on the cross because it is the only activity originating at the node. This entry is the LF for all activities (and the dummy) terminating at node 3.
4. At node 2 the smallest LS (8 from the dummy) is entered on the cross.
5. Latest start times for activities A and B are determined by subtracting their durations from their terminating nodes as $LS_A = 8 - 8 = 0$ and $LS_B = 8 - 5 = 3$.
6. At node 1 the entry is the smallest LS from A or B, $LS_A = 0$. Unless a mistake has been made in the backward pass, the initial project event will have the same entries on both bars of the cross.

Total float is a measure of the leeway or slack available in scheduling activities. As apparent in the sample networks, some activities have no leeway; they must start and finish at the given times if the project is to be completed at its calculated minimum duration. An activity with LS larger than ES has leeway. If $LS - ES = 2$, an activity can begin two time units later than its earliest start or it can take up to two time units longer to complete than anticipated without delaying the project completion. Total float is evident for activities B ($LS_B - ES_B = 3 - 0 = 3$) and D ($12 - 10 = 2$) in Figure 6-11. The same values could be obtained from the network by using the latest start and finish times: Total float of B = $TF_B = 8 - 5 = 3$ and $TF_D = 14 - 12 = 2$.

The chain of activities stretching from the first to last event with no float is known as the *critical path*. There may be several parallel critical paths in a project. In Figure 6-11 the critical path goes from node 1 to 2 to 3 to 4. It is easily identified by crosses with the same entries on both bars and is often marked by double lines to give added emphasis. A delay in starting or completing any of the critical activities will cause a corresponding delay in the project duration unless corrective action is taken.

A summary of start, finish, and float times is given in a boundary timetable. One format for a boundary timetable is shown in Figure 6-12. When calculations are performed by a computer, the printed results follow closely the shown format. Additional information such as calendar dating, near-critical paths, and resource data are included on some computerized printouts.



CPM BOUNDARY TIME TABLE: SURVEY PROJECT

| | | EARLIEST | | LATEST | | TOTAL | |
|---|---|---|---|---|---|---|---|
| ACTIVITY | DESCRIPTION | START | FINISH | START | FINISH | FLOAT | CRITICAL |
| A-(1, 2) | Approve survey | 0 | 8 | 0 | 8 | 0 | * |
| B-(2, 4) | Hire canvassers | 8 | 13 | 11 | 16 | 3 | |
| C-(2, 3) | Design questionnaire | 8 | 16 | 16 | 8 | 0 | |
| D-(2, 6) | Select households | 8 | 11 | 18 | 21 | 10 | |
| (3, 4) | Dummy | 16 | 16 | 16 | 16 | 0 | |
| E-(4, 6) | Train canvassers | 16 | 21 | 16 | 21 | 0 | |
| F-(3, 6) | Publicize survey | 16 | 20 | 17 | 21 | 1 | |
| G-(3, 5) | Print questionnaire | 16 | 19 | 18 | 21 | 2 | |
| (5, 6) | Dummy | 19 | 19 | 21 | 21 | 2 | |
| H-(6, 7) | Conduct survey | 21 | 28 | 21 | 28 | [illegible] | |
| I-(7, 8) | Analyze results | 28 | 40 | 28 | 40 | [illegible] | |

*Fig. 6-12. Arrow network completed for manual time calculations for the survey project. Results are summarized in the boundary timetable.*

## PERT

During the same years CPM was being launched, a different group introduced a closely related method called *program evaluation and review technique*. Its initials make the snappy name PERT. The technique was created to better manage and thereby reduce the development time for new weapon systems. It was first applied to the development of the Polaris ballistic missile where it was credited with being instrumental in the exceptionally short period it took the Polaris to become operational. Since its introduction, PERT has found a secure place in management's vocabulary and practices.

The initials PERT and CPM are frequently used indiscriminately to describe network scheduling. Both rely on networks and involve essentially the same calculation procedures, but their basic intents differ. CPM was developed for applications to familiar projects where activity durations and costs are well known. PERT was designed for use in research and development projects where there is considerable uncertainty about what must be done and how long it will take to do it. Consequently, PERT uses statistical methods to establish activity durations and to predict the probability of meeting project completion dates.

### Expected Time for Activity Completion

In industries such as aerospace many production problems are encountered that have never been faced before. When nonstandard products depend on technological innovations, knotty design problems and technical frustrations typically cause delays. The reverse also occasionally happens when a sudden technological breakthrough saves a large chunk of time. The PERT system of time estimation recognizes this uncertainty by combining three time estimates to form a single expected activity duration. The three are

1. *Optimistic time (a)*—The shortest possible time in which the activity may be completed under ideal conditions.
2. *Pessimistic time (b)*—The length of time required if unusual complications or unforeseen difficulties arise in conducting the activity.
3. *Most likely time (m)*—The duration that would occur most often if the activity were repeated many times under the same conditions.

A qualified person should make these time estimate ranges, just as in determining single activity durations for CPM applications. Of course the outside estimates of pessimistic and optimistic durations should not include remote possibilities of earthquakes, floods, fires, or other highly unusual catastrophes.

But they do include all the bad or good breaks which might occur as seldom as one in a hundred times. The most likely estimate lies between $a$ and $b$, but is not necessarily centered between the two.

An *expected time* ($t_e$) is calculated by weighting the three time estimates according to the formula below.

$$\text{Expected time} = t_e = \frac{a + 4m + b}{6}$$

As the name implies, the expected time is the average duration anticipated if the activity was repeated a large number of times. More specifically, $t_e$ is the mean of a distribution of possible durations where the mode $m$ is assumed four times more likely to occur than either $a$ or $b$.

To illustrate the concept of PERT times, suppose you wanted to decide how long it would take for you to originate and sketch a poster design for a campaign to sell bikinis. If you had a sudden brainstorm you might get it done in, say, two hours. At the other extreme, say, you might fuss with it for 20 hours before you were satisfied. After pondering the question, you might estimate that the most typical time for the activity would be one working day, eight hours. The expected time for the poster sketch would then be

$$t_e = \frac{a + 4m + b}{6} = \frac{2 + 4(8) + 20}{6} = 9 \text{ hours}$$

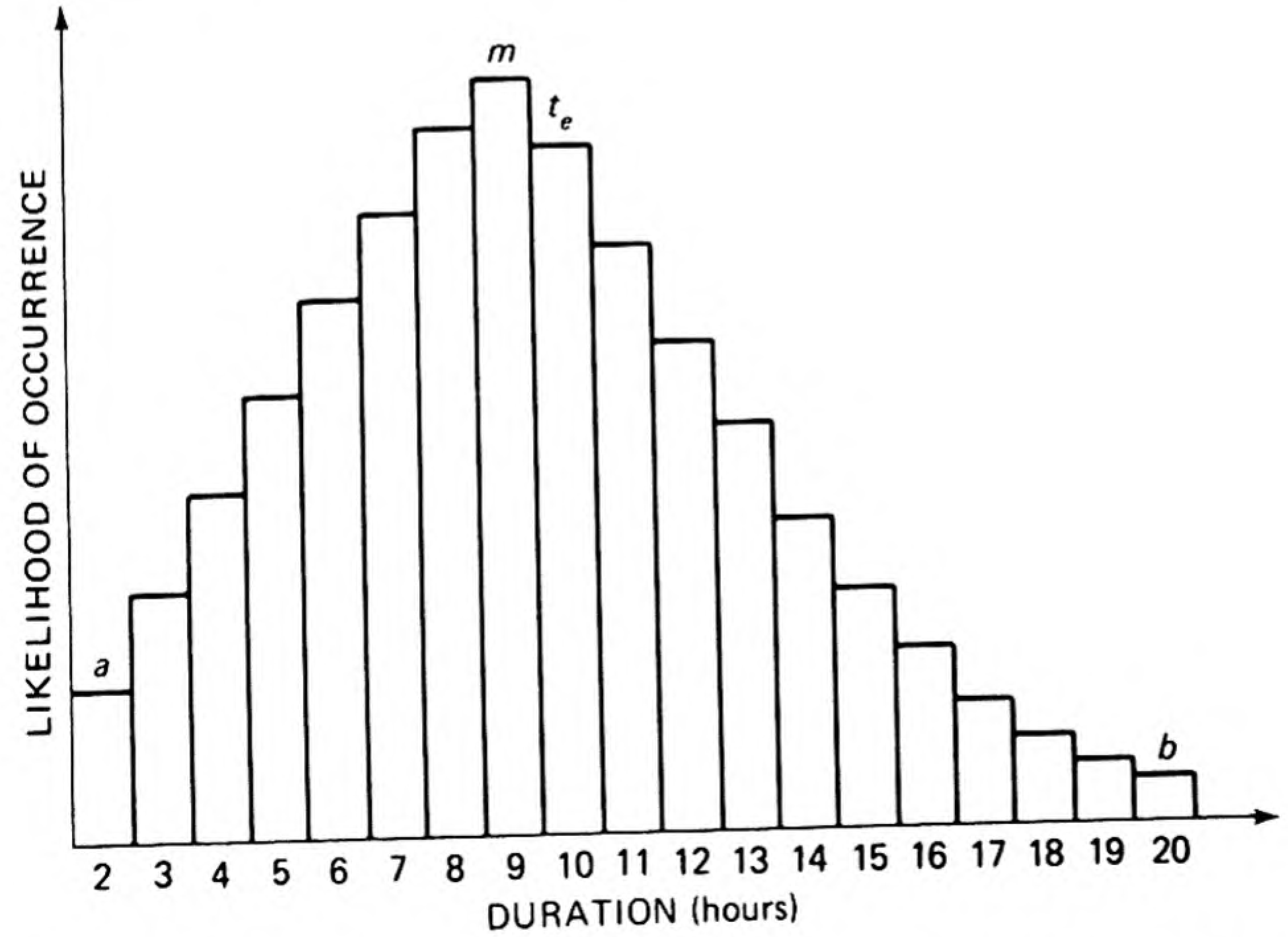


*Fig. 6-13. Distribution of possible durations for the activity "Design poster."*

The distribution of possible durations and their relative measure of occurrence would take the shape shown in Figure 6-13. Note that the bars to the left of $t_e = 9$ account for the same total likelihood of occurrence as those to the right of the nine-hour bar. That is, there is a 50/50 chance that the actual duration will be greater or less than nine hours. It is also implied that a duration of less than two hours or longer than 20 hours is too unlikely to consider.

### Analysis of Expected Project Completion Times

After the expected times have been computed and a $t_e$ entered for each activity, network calculations proceed in the same manner as CPM. Computer programs are available to do the $t_e$ computations and to produce a boundary timetable. The applications for boundary times are identical in CPM and PERT.

One detail unique to PERT analysis is the potential for calculating the probability of completing an event ahead of schedule. Each activity in the network could have a different *variance*, a measure of the spread between the optimistic and pessimistic time estimates. As suggested in Figure 6-13, there is a 50 percent chance an activity will take less time to complete than its expected duration even without applying extra resources to speed it up. Of course, there is an equal chance it will take longer too. These conditions lead to the conclusion that any event on the critical path has a 50 percent chance of meeting its calculated start time. Logically it has less than a 50/50 chance of meeting a start time under the total of the $t_e$'s of all critical activities leading to the event, but it still has some chance of finishing early. Formulas based on variances are available to calculate this probability. The event used in the calculations is called a *milestone*.

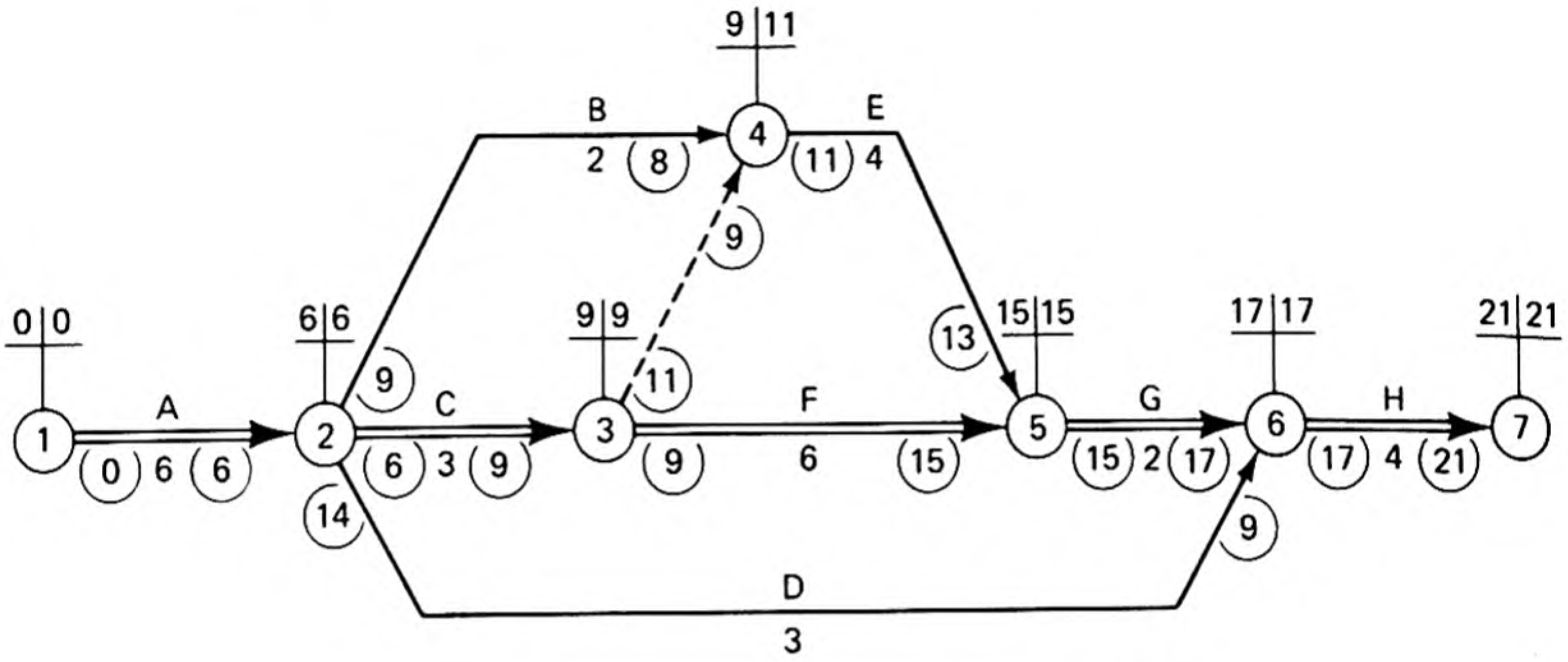
Milestone probabilities may assist management decisions about a project. For instance, a project leader might want to know what the chance is that a certain milestone event will be reached by a critical reporting date, or he might need to know how many days should be added to the project duration to have the probability of completion raised to, say, 0.9. Such uses of milestone probabilities provide an insight into the balance between risk of schedule slippage and the application of additional resources. Although we will not pursue the formulas for calculating probabilities, it is interesting to note that in the example of PERT computations in Figure 6-14, the probabilities for completing event 7 in 19, 21, and 23 weeks are, respectively, 0.84, 0.50, and 0.16.

## PROJECT MANAGEMENT

Network scheduling is a prime example of the value of graphic art to management. The visual display has obvious worth in direct communication between

RESEARCH AND DEVELOPMENT PROJECT
(Design and test of DOOZIAC MII)

| | | TIME ESTIMATES (weeks) | | | |
|---|---|---|---|---|---|
| ACTIVITY | POSTREQUISITES | $a$ | $m$ | $b$ | $t_e$ |
| A-(1, 2) | A < B, C, D | 4 | 5 | 12 | 6 |
| B-(2, 4) | B < E | 1 | 1 | 7 | 2 |
| C-(2, 3) | C < E, F | 2 | 3 | 4 | 3 |
| D-(2, 6) | D < H | 3 | 3 | 3 | 3 |
| E-(4, 5) | E < G | 3 | 4 | 5 | 4 |
| F-(3, 5) | F < G | 1 | 7 | 7 | 6 |
| G-(5, 6) | G < H | 1 | 2 | 3 | 2 |
| H-(6, 7) | | 3 | 3 | 9 | 4 |



PERT BOUNDARY TIME TABLE: DOOZIAC PROJECT

| | | EARLIEST | | LATEST | | TOTAL | |
|---|---|---|---|---|---|---|---|
| ACTIVITY | DESCRIPTION | START | FINISH | START | FINISH | FLOAT | CRITICAL |
| 1, 2 | Complete design | 0 | 6 | 0 | 6 | 0 | * |
| 2, 4 | Layout mechanical | 6 | 8 | 9 | 11 | 3 | |
| 2, 3 | Layout electrical | 6 | 9 | 6 | 9 | 0 | * |
| 2, 6 | Train operators | 6 | 9 | 14 | 17 | 8 | |
| 3, 4 | Dummy | 9 | 9 | 11 | 11 | 2 | |
| 3, 5 | Build controls | 9 | 15 | 9 | 15 | 0 | * |
| 4, 5 | Fabricate frame | 9 | 13 | 11 | 15 | 2 | |
| 5, 6 | Assemble prototype | 15 | 17 | 15 | 17 | 0 | * |
| 6, 7 | Test prototype | 17 | 21 | 17 | 21 | 0 | * |

*Fig. 6-14. PERT applied to a research and development project showing expected time data, network calculations, and boundary times.*

project managers, supervisors, and workers; all of them see the same picture of anticipated action and they can discuss it in the well-defined terms associated with networks. Less obvious but perhaps more important is the built-in requirement for thorough planning to precede the scheduling. Individual errors of logic, both of omission and commission, become painfully evident after they appear on paper as part of a total, supposedly integrated, project pattern. The simple act of exposing thoughts to a formal procedure of expression tends to better understanding.

### Use of Computers

Hand calculations were mentioned in this chapter more often than were machine calculations. One of the reasons for emphasizing manual methods was to reveal the meaning of boundary times. Another reason is that managers should realize how they can take advantage of network-scheduling techniques with just a scratch pad and pencil. A diagram sketched on the back of an envelope may be the map needed to discover a better way to start things or to rescue a slipping project.

A decision to use a computer depends on the facilities available, the technical training of persons involved, the scope of the project, and the size of the network. It has been suggested that networks larger than 250 activities or 150 events are likely candidates for computerization. Even smaller networks are routinely computerized when computer capabilities are easily available. A major advantage gained from consigning calculations to a computer is the ease with which the project can be updated. As a project gets underway there are usually several minor variations that cause changes in activity sequencing or durations. A schedule is updated by making the changes that reflect current conditions to see how they affect future requirements, Since updates may be needed as often as once a week, the updating process is quickened by revising the original data stored in the computer and calling for a printout showing the effects of the revisions.

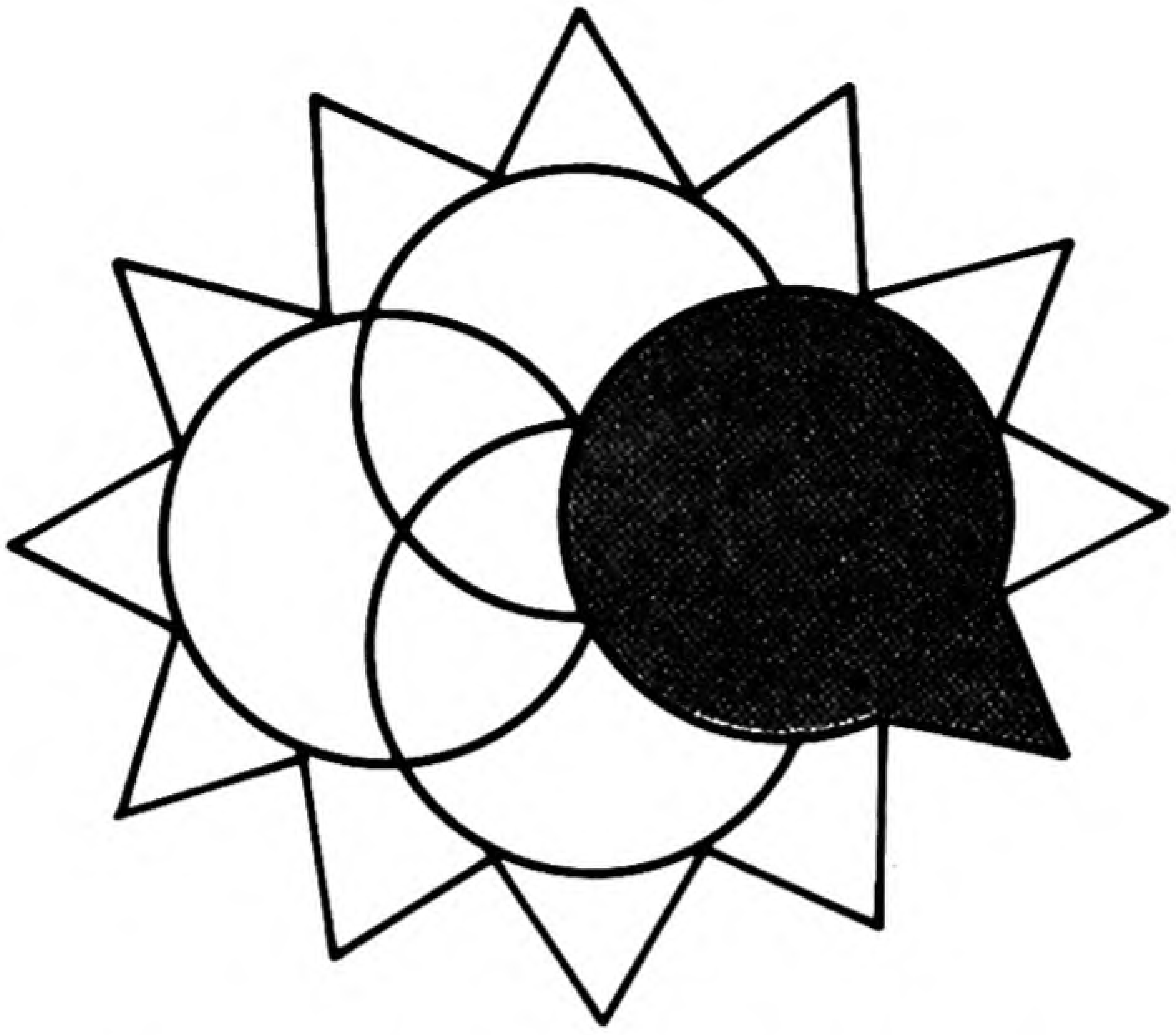
When a project is in danger of serious time delays, a computer can be used to simulate different ways to counter the trouble. Attempts to recover time take one or both of two means: (1) changing the sequence or objectives of activities and (2) increasing resources applied to the project, or diverting resources from activities in the project with a large amount of float to those with no float. Both courses involve risk. For instance, depriving a noncritical path of the resources normally given to those activities may transform them into a new critical path. Different possibilities can be processed by the computer as if the contemplated changes had actually been made. When a network is used in this fashion, it becomes a simulation model by which the consequences of change can be projected.

### Extensions of CPM and PERT

Innumerable modifications have been made to the basic CPM and PERT procedures to make them more useful for particular applications. The library of CPM and PERT computer programs includes printout formats for listings by event numbers, degrees of criticalness of different paths, latest completion dates, departmental responsibility, and many others. A computer can generate bar charts based on a network. Hand-drafted scheduling charts have been developed to picture cost allocations, resource assignments, and management responsibilities by color coding or special notations. Skeletal arrow networks are employed as reporting forms in some organizations, especially for reporting plans to upper levels of management.

New uses of CPM and PERT are reported regularly in management journals. Some of the developments are purely technical, but many suggest clever ways that network analysis can help basic planning and the scheduling of even the smallest projects. In Chapters 8 and 11 we shall see how network-based methods can assist project control.

# Chapter 7



# Operating

**KEY SUBJECTS**

*Productivity improvement is a management responsibility.* Gains can be made from automating production lines by using new technology such as computer-controlled processes and robots, and by assuring fuller use of human abilities.

*Time and motion studies have been used for over half a century to improve worker operations and to measure work accomplishments.* Method improvement starts with a survey of current conditions. The work place and the operator's practices are analyzed to eliminate unnecessary motions, to minimize necessary motions, and to make movements more effective. An operation is broken down into work elements to determine its standard time of performance. Timing can be done with a stopwatch, from films, by work sampling, and with predetermined time systems. Which timing method is preferable depends on the situation being investigated. Because faulty time standards can be so troublesome to a manager, it is essential that they are competently developed.

*Process studies are conducted to improve the sequence and coordination of operations.* Flow-process charts are used to track the flow of materials, information, or components through a system. The path is then examined to see if operations can be eliminated, combined, or done easier. Jobs can sometimes be made more satisfying by expanding the number and variety of operations included or by increasing the responsibilities assigned. Job enlargement counters over-standardization by improving motivation through enriching the work content.

*Better environmental conditions such as adequate illumination and noise control contribute significantly to improved work performance.* Human-factors studies concentrate on environmental conditions that enhance man's decision-making abilities. The purpose of controlling environmental factors is to make workers comfortable and to protect them physically.

*Safety, a managerial problem, is receiving increasing attention.* Strong new laws are being enacted to protect the employee at his work place. Unsafe acts by workers and unsafe working conditions cause injuries. Managers can help prevent injuries by supporting a complete safety program. Injuries are investigated to determine their cause in order to redesign work practices or the work place to prevent a recurrence of the accident. A safety program is a joint effort that depends for success on the cooperative participation of both management and workers.

## PRODUCTIVITY

*Operations,* in an industrial sense, usually implies the factory floor, the office, the work shop, the routine but vital jobs of production. The plans for improvement which come from executive suites are supposedly directed toward improving performance at the operating level. Here the firm spends most of its money. And here is also where the firm makes most of its money. A high quality firm has high quality operations.

Economists generally define productivity as output per man-hour. In most U.S. industries, the goal is to produce more—more than last year or more than some other company. These industries produce by means of man-hours—not just by men or by hours but by man-hours. In other words, in order to increase productivity, the effective manager must get more output per man per hour. He might just put more men on the job in order to accomplish this kind of output. But that gets expensive. He might get his men to work longer hours, but overtime also gets expensive. So by good management of several elements such as sound planning, wise investments, use of new technology, more efficient use of time, and greater attention to job satisfaction he expects to increase productivity.

Productivity in the U.S.A. since 1890 has consistently increased as shown in Figure 7-1. Rates have varied owing to business booms and busts, wars, economic policies, technological advances, and many other factors. The relatively low productivity in this country from 1965 to 1970 aroused concern among legislators who established new commissions and held hearings to investigate causes of the downturn. Numerous reasons were suggested: changes in demand from manufactured goods to more services, new social values, a

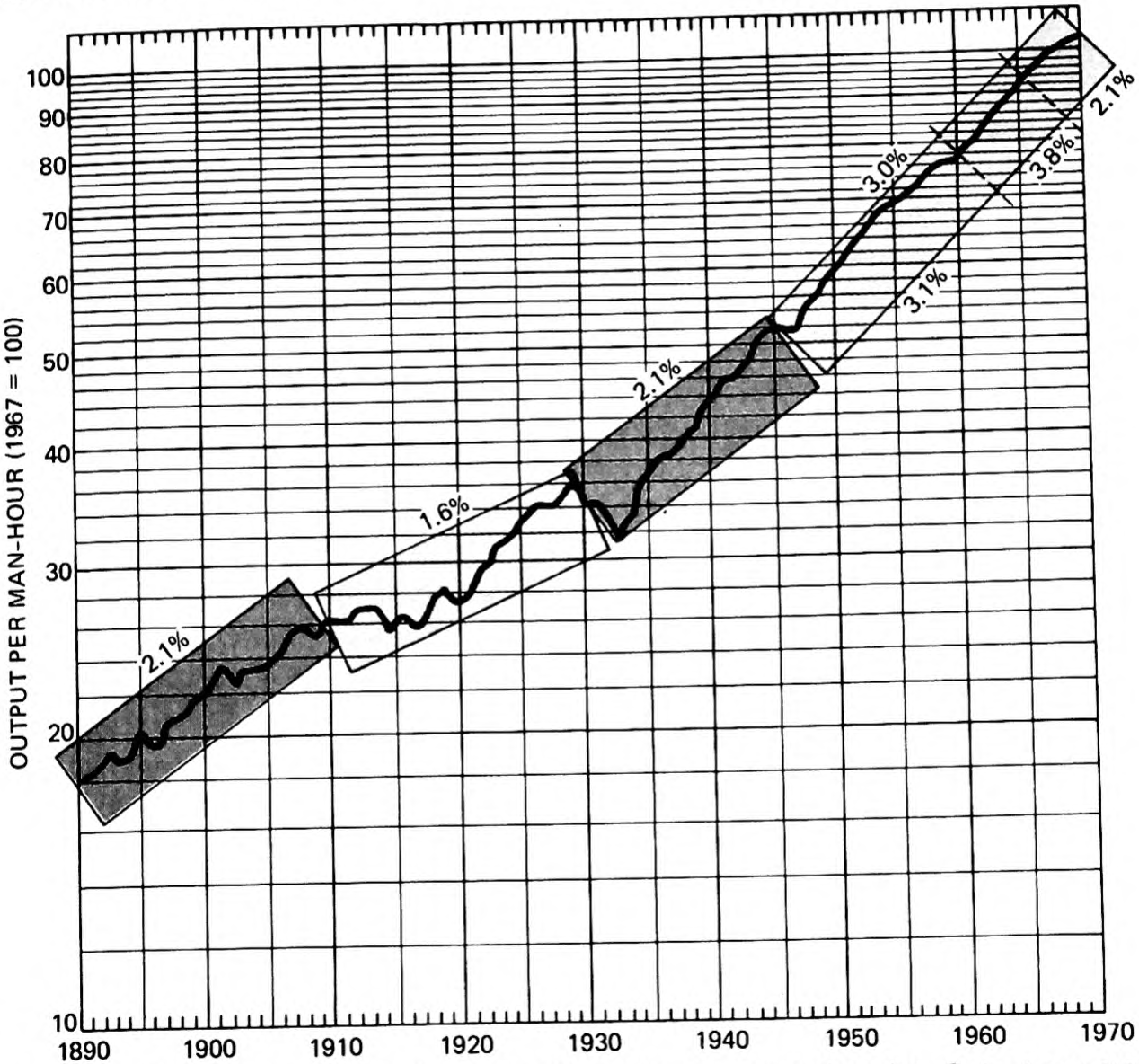


*Fig. 7-1. Productivity gains in the United States for the last 8 decades. Output per man-hour rose at a compound annual average of about 2% during the first 55 years and then accelerated to about 3% for the next 25 years. During the period 1965-1970 when U.S. productivity increased at an average rate of 2.1%, productivity was increasing 5.3% in Germany, 6.6% in France, 7.9% in Sweden, and 14.2% in Japan.*

different attitude toward work by the new generation of employables, too much industrial capacity built up before the recession of 1970 to 1971, and changes in the age-sex mix of the labor force.

### Automation, Automatons, and Computers

Manufacturing systems relying on automatic processes or self-operating machines have contributed hugely to productivity. It is hard to believe that only a few years ago such automation was considered a menace. People were afraid that machines would deprive workers of their jobs. Now automation is considered socially desirable; the assumption is machines will do the tedious, unpleasant jobs and free workers to do more challenging assignments. Somewhere between the old and new views is the actual situation—some unpleasant jobs have been transferred to machines but some skilled workers have concurrently been replaced.

Conventional automation has been based on large, expensive machines that operate in fixed positions to produce unvarying products. A more versatile form of automation was introduced in the 1950s when electrically controlled machines were developed to perform machining operations in accordance to punched tape instructions. The trend toward "soft" automation continues today with computers programmed to control machines that move materials around a factory, store and retrieve items in warehouses, perform inspections, and even issue directions to people working in a plant or office.

A fascinating new aspect of automation is the use of robots. Though they bear little resemblance to humans, they do possess manlike characteristics of flexible arms that can be set to work on a wide variety of tasks. As now used in industry they perform such routine and laborious work as feeding presses and machine tools, stacking bricks, and welding auto bodies. The main appeal of robots as tools to increase productivity is that they are adaptable. They can be easily reprogrammed to do completely different types of work within their basic capacities. The hitch is their limited capabilities. Besides present problems of low reliability and high cost, which probably can be overcome, robots are blind and stupid; they cannot sense and react to any changes from standard conditions or disruptions in their programmed pattern of performance. Still, an automaton's capacity to do dangerous jobs and menial or distasteful tasks ensures continued interest in the development of robots and artificial intelligence.

### People Pleasers

Another way to raise productivity besides adding mechanized and computerized assistance to the work place is to make the job itself more attractive. The rather tired motto, "work smarter not harder," promoted by work simplification campaigns is still a very effective means of increasing output with little or no investment in expensive equipment. People start out or lapse into poor work habits. Correcting these time- and energy-wasting activities can yield surprising dividends in better output. Sometimes it is necessary to redesign a job completely. The new version may use a better layout for the work. More convenient motion patterns or a wider range of activities may offer more challenging and interesting assignments. There is no way a manager can force people to be happy or to take more pride in their work, but he can arrange working conditions to encourage pride and satisfaction.

Many other factors largely controllable by managers contribute to work performance. Both outgoing products and incoming materials can be standardized to some extent. Inspection procedures to assure uniform quality for materials supplied to operators are well established, but standardization of finished products is far less extensive. For instance, a warehouse of one food chain carries 2,500 different sizes and shapes of shipping cartons: less variety would greatly simplify storage and material-handling problems. Proper attention to the flow of supplies and parts reduces work delays. Enough light, not too much noise, fresh air, and comfortable temperatures are conducive to a happier work force. Elimination of injury-provoking conditions reduces accidents that hurt morale as well as productivity. These are seemingly routine but often neglected factors that prevent worker frustrations. They are the topics for the following sections.

## WORK METHODS, MOTIONS, AND MEASUREMENTS

Improved productivity could start from showing an operator that his work would be done easier and faster by just changing his grip on a tool or by using a smoother arm movement to pick up a part. Such simple refinements are individually insignificant, but when the operation is repeated hundreds of times a day, even a tiny saving is magnified to respectable proportions. Frank Gilbreth, the pioneer investigator, defined motion study as "the science of eliminating wastefulness resulting from using unnecessary, ill-directed, and inefficient motions;" and time study as "the art of recording, analyzing, and synthesizing the time of the elements of any operation, usually a manual operation, but it has also been extended to mental and machinery operations."[1]

The two studies obviously complement each other. Motion analysis perfects the way an operation is done, and time measurements encourage compliance to the improved method. Standard times for operations done in the "one best way" are developed both to assist work scheduling and as a basis to set wages. Although time and motion studies are often associated strictly with factory operations, they are just as widely applied to clerical, administrative, and service functions. Any operation that is repeatedly conducted in essentially the same way is a candidate for method improvements and timing.

### Studies to Precede Studies

It costs money to save money. A study should be made before launching a method-improvement program to determine whether benefits can be expected to exceed the costs of the program. An extra advantage gained from a preliminary survey is the opportunity to explain to those involved in the study what the purposes are. People naturally get apprehensive when they learn they are to be studied. Relieving this tension is important to the investigator. He can improve human relations, and he can get a lot more help from a cooperative subject than he can from one who is "up tight."

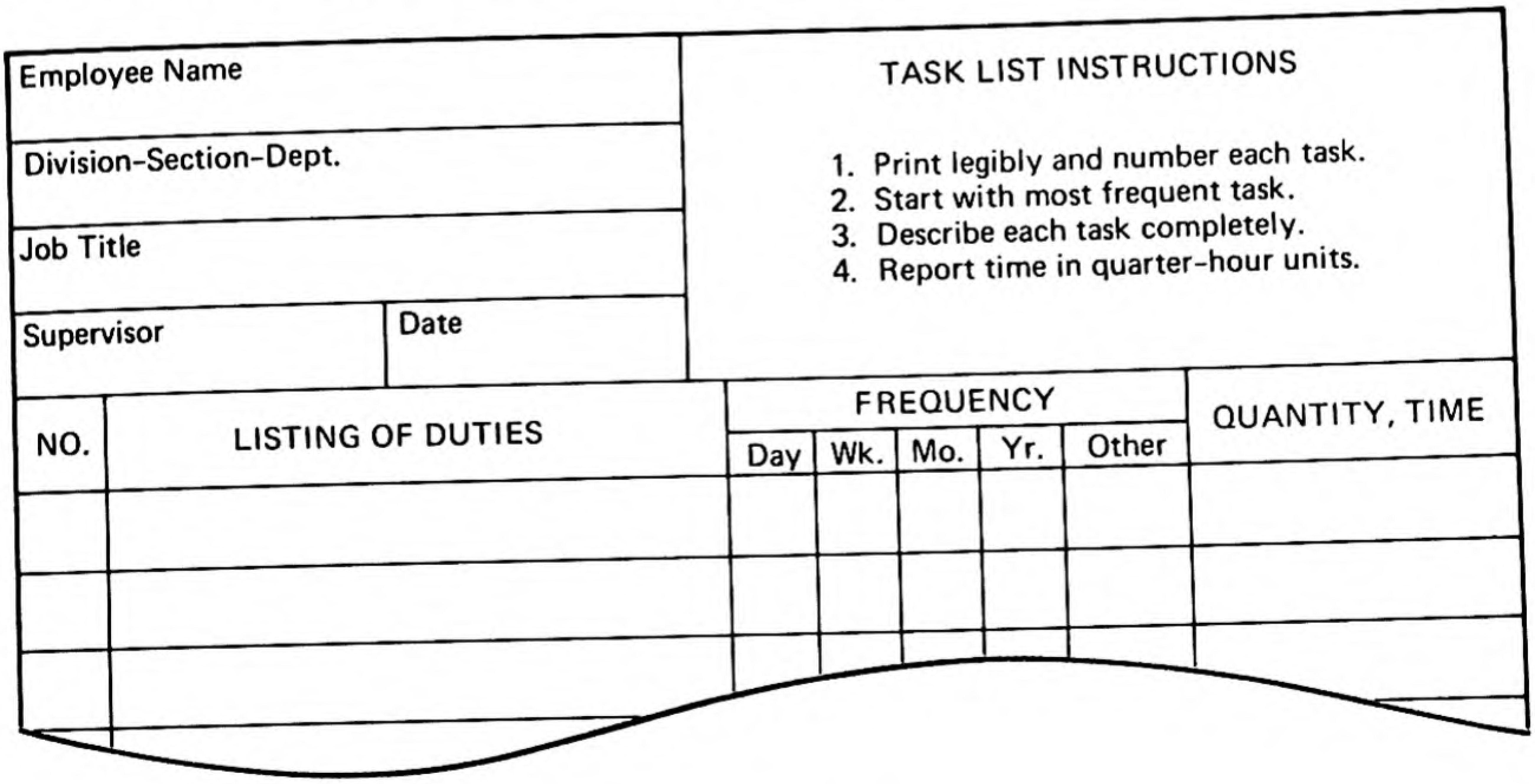
Requests for a study are usually initiated by the manager of an administrative unit and go to a systems analysis or industrial engineering department. The manager might have just a general suspicion that methods could be improved, or he could have a specific problem. As an example, the administrator of an office might be aware that a new reporting system to be installed will require different and perhaps more time-consuming practices. He requests a study to develop standard operations for meeting the new requirements. In the preliminary survey the office workers are informed of what to expect and their suggestions are sought for ways to meet the new situations. The survey thus reveals what study areas to concentrate on and the potential savings that could result.

Another use of a prestudy arises when a major operation is to be undertaken. A major move necessarily depends on many minor moves. By observing how the present operation works by and associating this information with the planned change, a manager can make a smooth transition with little lost time. Studies preceding the combination of two hospitals into one administrative unit provide examples. One study was directed at the flow of personnel between the two hospitals to determine transportation needs. This study was linked to the flow of material between the two units. Both of these studies relied on other studies made to determine which labs should be combined, which hospital should retain laundry facilities because only one laundry was needed, which one should contain the administrative offices, etc. There was not enough time to make a thorough study of each question. Just enough information was obtained in each case to satisfy the basic problem. After the total move was laid out, intensive studies were made to perfect each individual operation in conformance with the overall objectives.

Interviews are usually the most productive means of gathering information. Skillful interviewing is an art that comes naturally to some and never seems to be mastered by others. It involves selling a solution even as the facts are being collected. An interviewer always finds something to admire as he solicits suggestions as to what facts are needed, how to get them, probable solutions, and what should be done about national politics or the over-crowded parking lot. Every interview is intentionally aimed at securing facts and making a friend.

Inspecting the work place and leaving record-keeping forms with operators yields additional information. By closely examining files, counting completed and in-process work, noting the contents of reject or waste containers, and observing current practices, an investigator gets an impression of the entire work environment and may even be able to make some immediate minor improvements. Revealing facts are also secured from work distribution or duty description forms filled out by an operator. A task list form as shown in Figure 7-2 supplies a rough measure of the time a worker spends on different duties. This device gathers information on such questions as:

- Which duties take the longest time to complete?
- What type of work occurs most frequently?
- Which tasks are spread too thinly or are unrelated?
- Which duties are less important, duplicated, or unnecessary?



Employee Name

Division-Section-Dept.

Job Title

Supervisor
Date

TASK LIST INSTRUCTIONS

1. Print legibly and number each task.
2. Start with most frequent task.
3. Describe each task completely.
4. Report time in quarter-hour units.

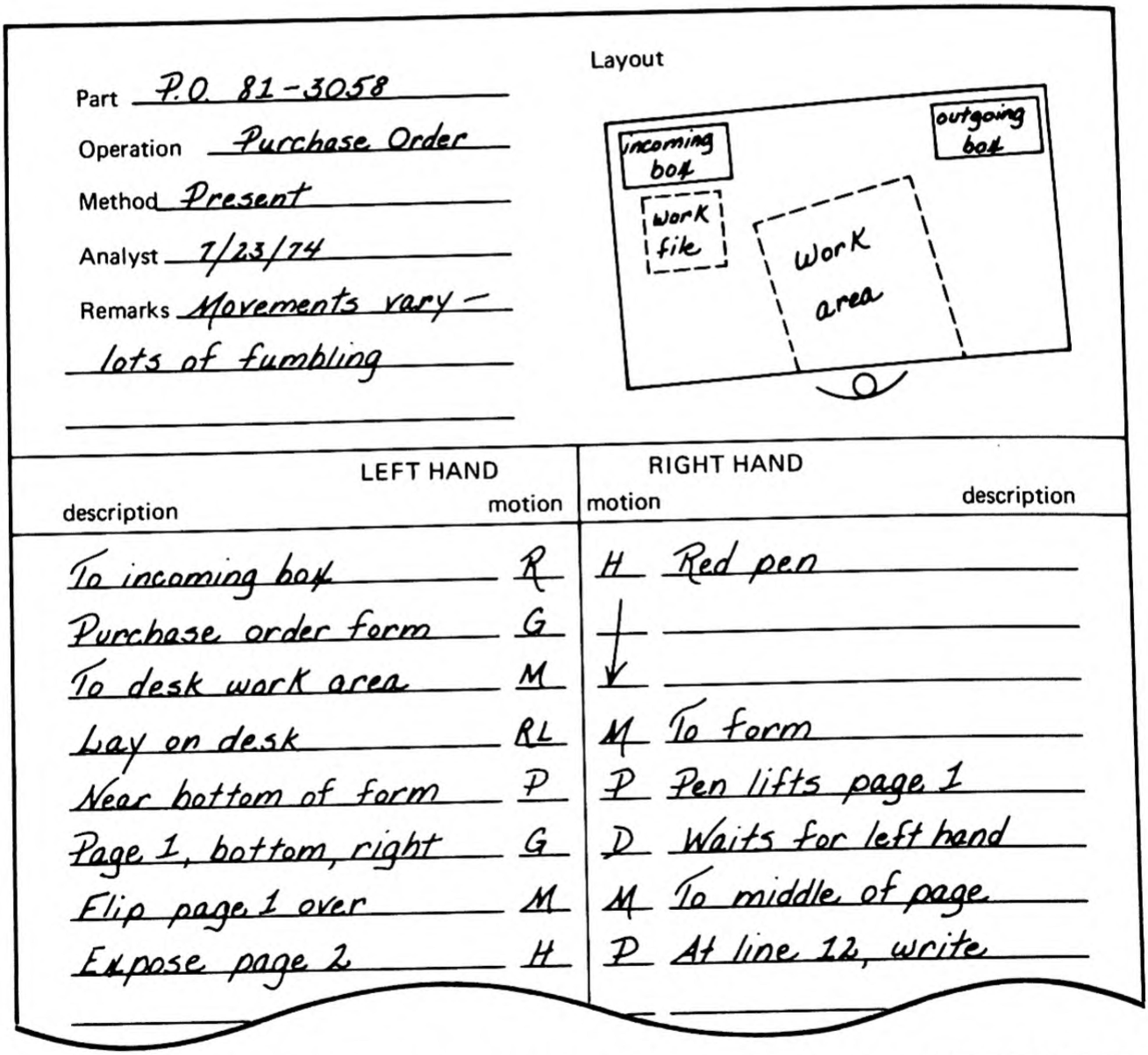
| NO. | LISTING OF DUTIES | FREQUENCY | | | | | QUANTITY, TIME |
|---|---|---|---|---|---|---|---|
| | | Day | Wk. | Mo. | Yr. | Other | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Fig. 7-2. *Task list form to be completed by an operator in a preliminary survey.*

### Motion Economy

The purpose of motion study is to make work easier and more productive by improving manual motions. This goal may seem so obvious in intent and so simple to accomplish that one wonders why it is worth attention. It would be unnecessary if people naturally did things in the easiest, shortest way. But they do not. And worse, they usually keep right on following the same awkward motion patterns without questioning them. Motion principles are reminders about better ways to move.

Many rules and suggestions are available for applying motion analysis to jobs.[2] And each point is intuitively logical. All of them would be used automatically



Part P.O. 81-3058

Operation Purchase Order

Method Present

Analyst 7/23/74

Remarks Movements vary — lots of fumbling

Layout

incoming box
outgoing box
work file
Work area

| LEFT HAND description | motion | RIGHT HAND motion | description |
|---|---|---|---|
| To incoming box | R | H | Red pen |
| Purchase order form | G | │ | |
| To desk work area | M | ↓ | |
| Lay on desk | RL | M | To form |
| Near bottom of form | P | P | Pen lifts page 1 |
| Page 1, bottom, right | G | D | Waits for left hand |
| Flip page 1 over | M | M | To middle of page |
| Expose page 2 | H | P | At line 12, write |

*Fig. 7-3. Left hand–right hand chart of simultaneous motions required to check a purchase order. When an organization uses many purchase orders annually, a small time reduction in checking just one order can add up to significant savings in a year. The analyst might find that the boxes and files on the desk should be moved closer to the clerk, that a stamp could be used instead of a pen, that several forms could be piled on top of each other to permit continuous marking, or that the form should be redesigned.*

in designing a machine to do just one thing expertly, but each job has to be designed to make best use of human abilities. Thus the work place is adapted to serve the operator, and the operator is informed how he can best take advantage of the work place. Some of the general concepts of motion economy are collected in the following list:

1. *Eliminate unnecessary movements:* make one move serve two purposes —provide holding devices to free one or both hands—use a "drop delivery" to place things (just release an item in the general vicinity and let a gravity chute or spring action take it away)
2. *Minimize necessary movements:* reduce muscular effort by using prepositioned stops and mechanical guides—slide objects instead of lifting them—use color coding and prepositioned tools or materials to save search time—place most-used items within easy reach
3. *Make movements effective:* distribute activities among body members to best utilize natural capacities (for instance, use the leg to exert extra force or to free hands)—maintain body balance by using symmetrical motions and by avoiding sharp changes in direction—start and stop hands at the same time

Motion studies can be conducted by an observer just watching an operation or a film of it. When an operation deserves a detailed analysis, it is usually charted. The symbols used for a study of very small movements are listed below and a short operations chart using the symbols is given in Figure 7-3. By inserting a time scale between the left- and right-hand sections, the operations chart is converted to a SIMO (*si*multaneous *mo*tion) chart.

| **SYMBOL (MOTION)** | **DESCRIPTION** |
|---|---|
| R (Reach) | Moving an empty hand to within an inch of the intended position |
| G (Grasp) | Securing control of an object with the fingers |
| H (Hold) | Supporting an object while work is being performed on or by it |
| M (Move) | Moving a loaded hand to within an inch of the intended position |
| P (Position) | Aligning, orienting, or engaging one object with another |
| T (Turn) | Rotating the forearm about its long axis |
| D (Delay) | Hesitation while awaiting the completion of an act or event |
| RL (Release) | Letting loose of an object previously grasped in fingers |

The end result of a motion study may lead to an entirely new method of doing things. A study is limited only by the knowledge and creativity of the investigator. The suggestions for investigating discussed in Chapter 2 are appropriate guides to better method improvements. An incentive for continued diligence is the reminder that "habits take us where we were yesterday and complacency tends to keep us there."

### Time Standards

A time study is a partner to method improvements. The proof of an improvement is confirmed by a time reduction. Correspondingly, the completion time for a task is based on how long it should take while using the best motion patterns and workplace arrangement.

The need for time standards is apparent from reviewing the requirements for scheduling. Without established time durations for the work activities it would be almost impossible to coordinate production. A similar situation arises in setting wage payments, especially for incentive wages. You have to know how much can be accomplished under standard conditions before a fair compensation plan can be worked out. Cost estimating and labor cost controls also depend on knowing what output to expect from an input of time.

The definition of *standard time*—the time required by a qualified and fully trained operator to perform the operation by a specified method while working at a normal tempo—sets the routine for a time study. An operation is analyzed and redesigned if found inefficient. During the analysis the operation is broken down into work elements in the same way a project was divided into activities for critical-path scheduling. The work elements are then timed and the resulting readings are normalized to account for the operator's personal pace during the timing. Finally, allowances are added to compensate for unavoidable delays and to allow relief breaks. The end product is a realistic evaluation of labor accomplishment.

Timing can be done by an observer with a stopwatch, by counting frames of a filmed operation, by work sampling, or with predetermined time systems. The stopwatch method is the most common. Films are more appropriate for detailed studies where method improvements are anticipated. Work sampling relies on statistical techniques discussed in Chapter 12 to obtain the percentage of time men and machines are working or idle. The work-sampling method is based on the principle that samples taken at random from a large group tend to have the same distribution pattern as the group from which taken. For many situations work sampling is less expensive than continuous timing, and it has the added attraction of not involving stopwatches which tend to cause dismay among some workers.

Specialists can use tables of predetermined times for very minute movements to build a timed sequence of an operation.* Each method has its special attributes. For example, work sampling is best suited to evaluation of work performed by groups and predetermined timing is valuable for predicting how long an operation will take the first time it is done. Because faulty time standards can cause so much trouble for a manager in so many areas, it is essential to have competent advice.

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*Predetermined, or synthetic, times are carefully developed standard times for performing elemental motions such as a reach of 12 inches with an empty hand from a rest position to a fixed location should take about three-tenths of a second. The time to do a complete operation is determined by adding up all the elemental times comprising the operation. Two of the better known systems are Methods-Time-Measurement and Work-Factor Time Standards.

## WORK PROCESSES

A process study investigates operations of a size that fall between the micro elements used in motion analysis and the project breakdowns associated with network analysis. Each operation in a process could be subdivided into SIMO chart motions for the operator, or several processes could be collected to form one activity for a critical-path schedule. The purpose of a process study is to explore current operating procedures in expectation of designing better procedures. A study usually follows the flow of material, information, or components.

### Flow Process Charts

Charting of work process can take many forms as suggested by Figure 7-4. All versions track the flow of something through a system. The path portrayed is then examined to determine how it can be improved. The steps are checked to see if any of them can be

- *eliminated*—why is it done? Why is it done in the present order with the present equipment at the present location?
- *combined*—should changes be made in the material used, the product design, the work place?
- *done easier*—can moves be shortened, done faster, or be controlled better? Should someone else do it?

Five basic symbols are employed on most flow-process charts:

○ *Operation*—something acted upon or done
⇨ *Transportation*—something moved or moving
□ *Inspection*—something being examined or examining
D *Delay*—something stopped or waiting (temporary)
▽ *Storage*—something stored (intentional control)

Two symbols can be combined as in ⧈ which indicates that an inspection is conducted at the same time an operation is performed. Other symbols are occasionally adopted to show a specific function or, to describe particular

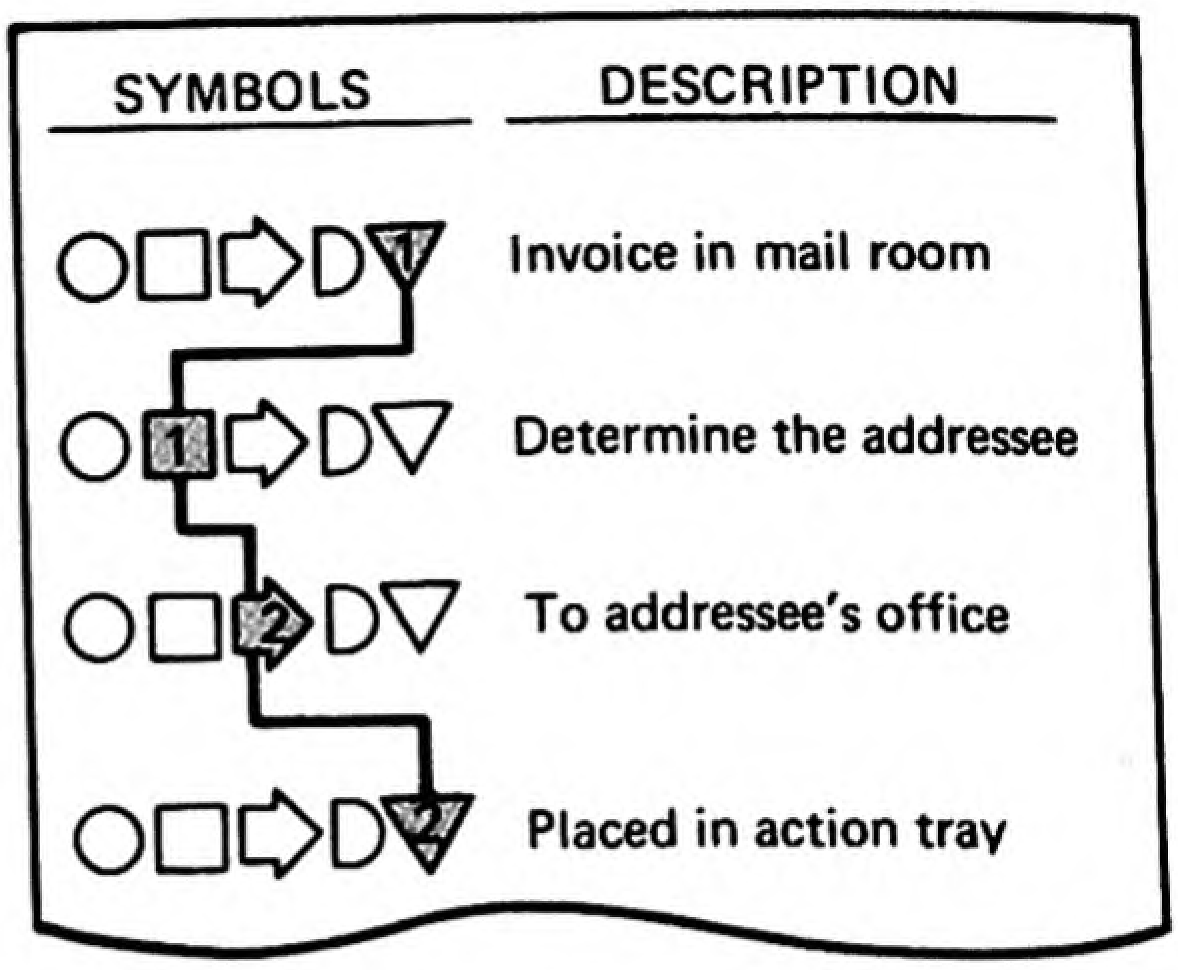
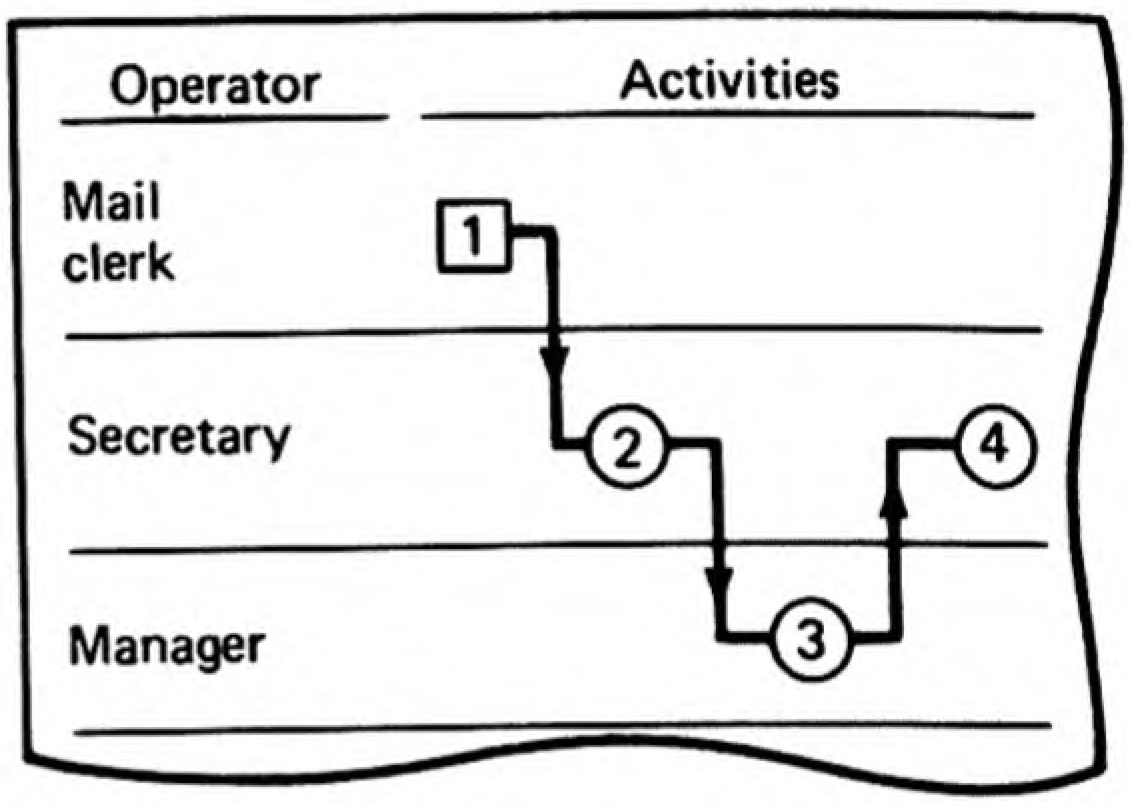
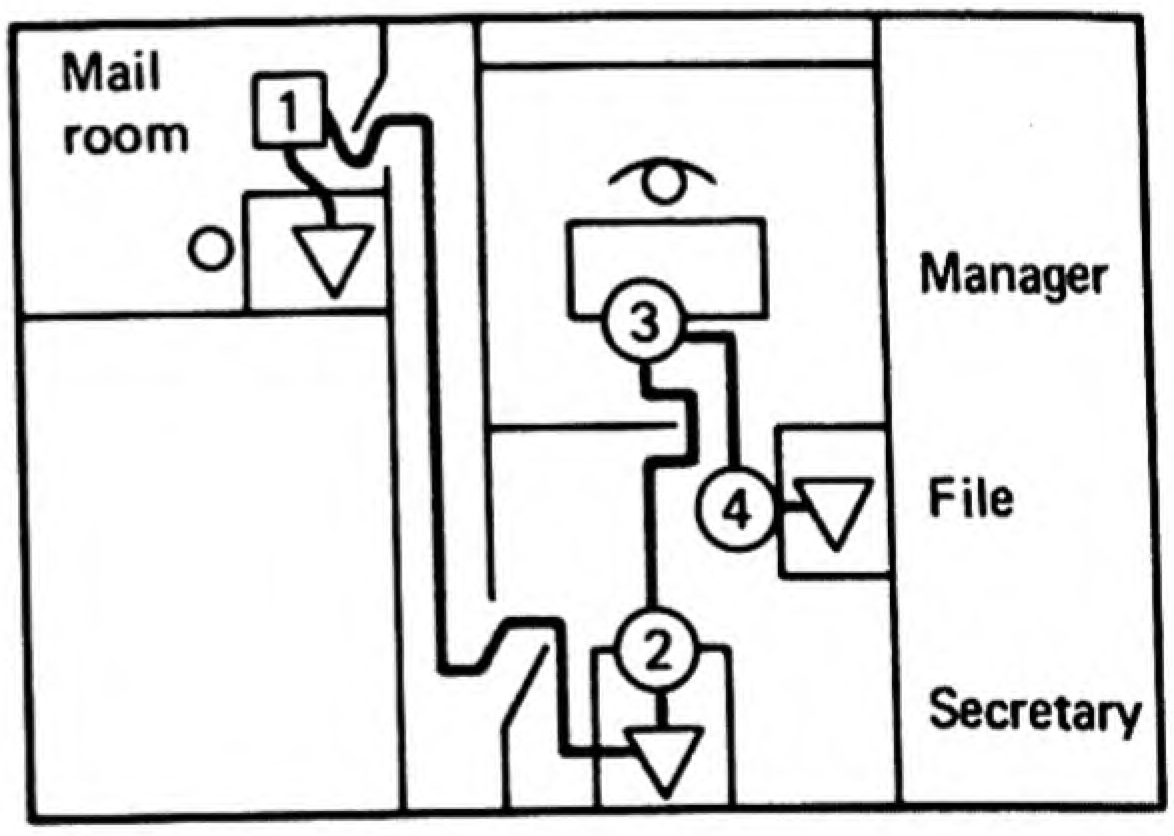
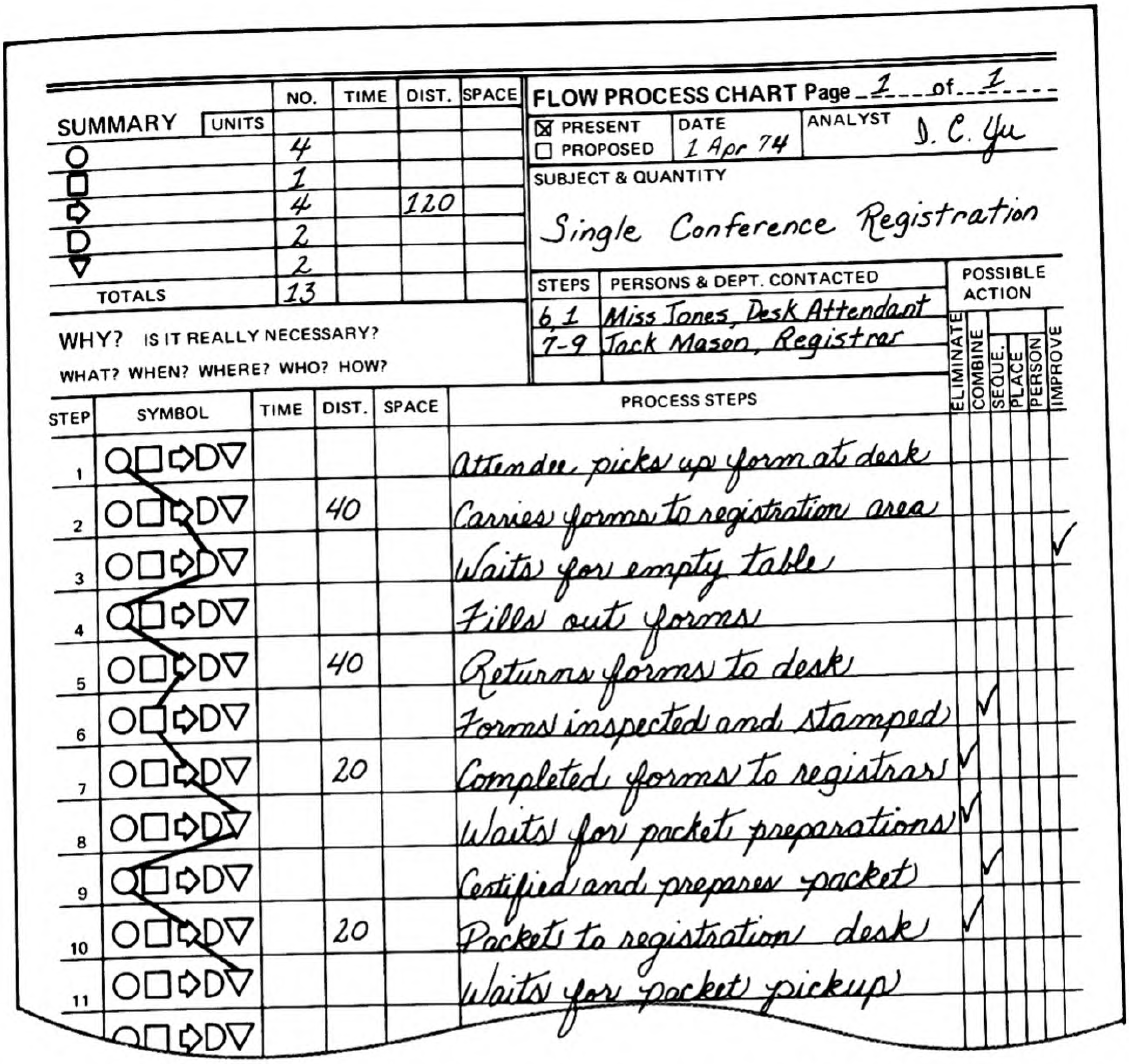
| TYPE AND PURPOSE | CHARACTERISTICS | EXAMPLE |
|---|---|---|
| *Single column*—to study the detailed steps in a relatively simple process | Charts are often drawn on printed forms; processes are shown by connecting appropriate symbols; space is provided for displaying additional data. |   SYMBOLS<br>DESCRIPTION<br>1<br>Invoice in mail room<br>1<br>Determine the addressee<br>2<br>To addressee's office<br>2<br>Placed in action tray |
| *Multicolumn*—to analyze detailed steps in the flow of work that is quite complex | Horizontal lines show operational areas; symbols are entered to show activities involved in the process. |   Operator<br>Activities<br>Mail clerk<br>1<br>Secretary<br>2<br>4<br>Manager<br>3 |
| *Layout diagram*—to improve the layout by avoiding unnecessary steps | Lines indicate the path of travel, and symbols show activities on a layout of the operating area (often drawn to scale). |   Mail room<br>1<br>3<br>Manager<br>4<br>File<br>2<br>Secretary |

*Fig. 7-4. Different formats for flow process charts using standard process chart symbols.*

applications, such as computerized information flow. The short descriptions that accompany the chain of symbols used in Figure 7-5 help clarify their meaning. Improper titles, skimping on words, or personal abbreviations thwart the purpose of the descriptions. The golden rule of charting is that everyone should get the intended meaning from the display.

### Job Enlargement

A feature that might emerge from studying a process chart of an operator's work is the repetitive nature of his activities. The concepts of specialization of



| SUMMARY | UNITS | NO. | TIME | DIST. | SPACE |
|---|---|---|---|---|---|
| ○ | | 4 | | | |
| □ | | 1 | | | |
| ⇨ | | 4 | | 120 | |
| D | | 2 | | | |
| ▽ | | 2 | | | |
| TOTALS | | 13 | | | |

WHY? IS IT REALLY NECESSARY?
WHAT? WHEN? WHERE? WHO? HOW?

**FLOW PROCESS CHART** Page 1 of 1

| | | |
|---|---|---|
| ☒ PRESENT<br>☐ PROPOSED | DATE 1 Apr 74 | ANALYST D. C. Yu |

SUBJECT & QUANTITY: Single Conference Registration

| STEPS | PERSONS & DEPT. CONTACTED |
|---|---|
| 6, 1 | Miss Jones, Desk Attendant |
| 7-9 | Jack Mason, Registrar |

| STEP | SYMBOL | TIME | DIST. | SPACE | PROCESS STEPS | ELIMINATE | COMBINE | SEQUE. | PLACE | PERSON | IMPROVE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ○□⇨D▽ | | | | Attendee picks up form at desk | | | | | | |
| 2 | ○□⇨D▽ | | 40 | | Carries forms to registration area | | | | | | |
| 3 | ○□⇨D▽ | | | | Waits for empty table | | | | | | ✓ |
| 4 | ○□⇨D▽ | | | | Fills out forms | | | | | | |
| 5 | ○□⇨D▽ | | 40 | | Returns forms to desk | | | | | | |
| 6 | ○□⇨D▽ | | | | Forms inspected and stamped | | ✓ | | | | |
| 7 | ○□⇨D▽ | | 20 | | Completed forms to registrar | ✓ | | | | | |
| 8 | ○□⇨D▽ | | | | Waits for packet preparations | ✓ | | | | | |
| 9 | ○□⇨D▽ | | | | Certified and prepares packet | | ✓ | | | | |
| 10 | ○□⇨D▽ | | 20 | | Packets to registration desk | ✓ | | | | | |
| 11 | ○□⇨D▽ | | | | Waits for packet pickup | | | | | | |
| | ○□⇨D▽ | | | | | | | | | | |

*Fig. 7-5. Flow process chart for current conference registration procedures. Process symbols are connected to show the sequence of registration activities and the flow of registration forms. Descriptions of the steps are developed from observation and from questions to the desk attendant and registrar. One obvious improvement would be to provide additional room for attendees to fill out registration forms. A more significant change would be to deliver registration forms with the packet preparation, thus eliminating two transportations and one storage delay.*

labor that were discussed in Chapter 1 have led to the creation of many jobs with short, recurring cycles that permit almost automatic performance and little or no mental direction. The advantages of such jobs to an employer are that less capable people can be hired at lower wages and little supervision is required because everything is standardized. There are also disadvantages. Workers on highly repetitive operations sometimes suffer from low morale that provokes absenteeism, malingering, high reject rates and breakage, and accidents.

Job enlargement has been successful in combating boredom in many repetitive work situations. It is not an automatic cure, but it is an alternative that has often proved capable of improving motivation and productivity with a modest investment in facilities. A token effort is seldom rewarding; a job enlarged by just having a worker fill a larger crate of melons than he had filled previously is a frivolous application. True job enlargement seeks to enrich a job in variety, interest, and significance.

In outward appearance jobs may be expanded horizontally and/or vertically. A horizontal expansion increases the number and variety of operations assigned to an operator to provide him with "a natural unit of work," one that reveals his contributions. Vertical enlargement brings the operator into the planning, scheduling, organizing, and inspecting responsibilities associated with his work. Less apparent, though still important, aspects of job enlargement include attention to group activities of operators and individual indoctrination of how each person's work is part of the total productive process. A worker may be taught how to do several related jobs besides his own, partly so that he can swap or fill-in and partly so that he can know the other job responsibilities. While the focus of job enlargement is on the scope and content of work, the thrust is toward worker satisfaction.

## WORK ENVIRONMENT

Human-factors engineering is the most recent extension of operation and process study. It has a relatively short history, starting in the early 1940s. Time and motion studies traditionally have dealt with man as a source of mechanical power. Human-factors studies switch the emphasis to man as a decision maker who uses his sensory, perceptual, and judgmental abilities to control machines. Out of this emphasis has grown a body of knowledge about how the environment can be controlled to enhance man's decision-making potential.

Many reams of data have been collected on human body measurements and limitations. We know limits to man's sensory detections, perceptual identifications, physical endurance, and many other characteristics. Managers on some occasions would be interested in the following recommendations:

- an illumination level of 100 footcandles is adequate for normal office work while 1,000 footcandles may be needed for "extra-fine" seeing tasks
- the noise level of an office should not exceed 45 decibels
- seating is most comfortable when the seat slopes at 6 or 7° and the backs slant at 100 to 112°
- dials and instruments can be read more easily when numerals are horizontal to the line of sight when they are read.

Considerations of the working environment as it affects man-machine operations are depicted in Figure 7-6.

Conflicting interpretations of human-factors research reports have caused some confusion in industrial application. Claims were once made that music played in a factory could dramatically alter the pace of production; now music is accepted only as a mood inducer or a mask for annoying small noises. While the mood effects of color are still debated, its value for improving identification is recognized. It has been proved that the standard typewriter keyboard is not the most efficient design, but the present design is so well established that it is not practicable to change it.

Before plunging into a new development to improve the work environment a manager should obviously seek expert help; and he should also remember that

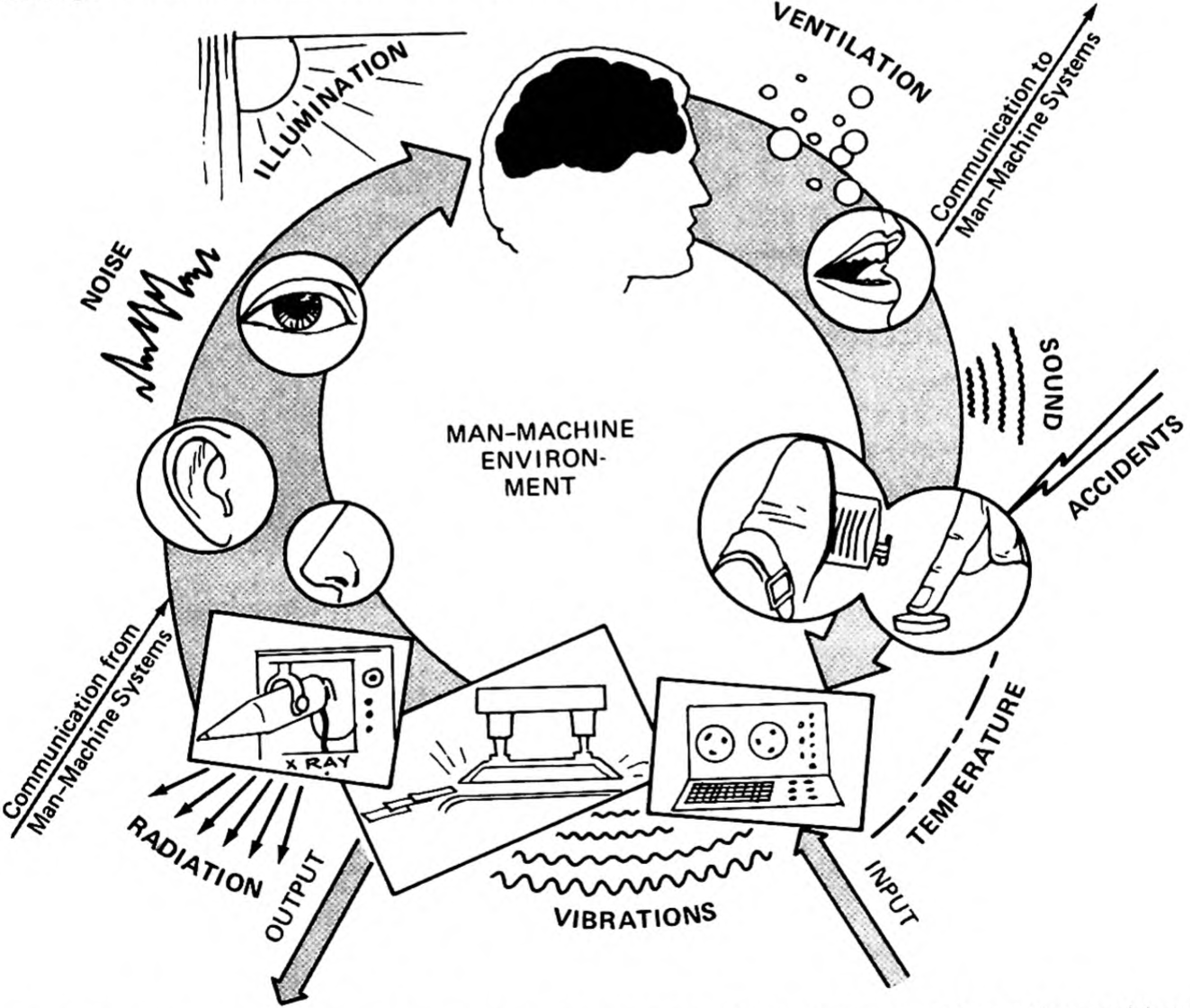

ILLUMINATION
VENTILATION
Communication to Man-Machine Systems
NOISE
SOUND
MAN-MACHINE ENVIRON-MENT
ACCIDENTS
Communication from Man-Machine Systems
X RAY
TEMPERATURE
RADIATION
OUTPUT
VIBRATIONS
INPUT

*Fig. 7-6. Influences on the man-machine environment. Man communicates with machines through controls and receives messages from machines via displays. His sensory abilities and his muscular activities are affected by the environment. A breakdown anywhere in the man-to-machine-to-man cycle can disrupt the system.*

physical working conditions are primarily intended to provide a safe, pleasant environment that does not interfere with work duties. It is doubtful that "color dynamics" or a "tailored sound system" will produce any sensational changes in productivity. They may help, but installing bigger lockers in the washroom or offering a broader menu in the company cafeteria might also do just as much. The whole concept of environmental design is to make people feel comfortable and to protect them physically.

## WORK SAFETY

Of all the work problems that should not be a problem, safety is foremost. Everyone benefits from a good safety record, and everyone loses from an injury. An employer with a reputation for safeness can attract workers easier, has lower insurance rates, loses less working time, has less damage to facilities and products, and generally escapes government-imposed fines and directives. Injuries can cause an employee to lose his savings, salary, position, optimism, and even his life. With so much at stake the wonder is that safety should still be a major problem, but abundant proof of its significance shows up each year in the statistics of lives lost, disabilities suffered, working hours missed, and medical bills paid. Accidents during the 1960s caused over 1 million deaths and 100 million disabling injuries, an increase of about 12 percent over the 1950s. The distribution of accidental deaths and death rates for 1970 and 1971 is shown below.

| | 1970 | | 1971 | |
|---|---|---|---|---|
| **SOURCE** | **NUMBER** | **RATE*** | **NUMBER** | **RATE*** |
| Motor Vehicle | 54,800 | 26.9 | 55,000 | 26.7 |
| Work | 14,200 | 7.0 | 14,390 | 6.9 |
| Home | 26,500 | 13.0 | 26,500 | 12.8 |
| Public | 22,000 | 10.8 | 22,000 | 10.7 |

*Deaths per 100,000 population.

Although work-related deaths are fewer than those experienced at home, on the highways, and at play, they are still a formidable challenge to managers. New laws are being passed to ensure increased attention to work safety. The Occupational Safety and Health Act which affects more than 57 million employees in over 4 million places of employment went into effect in 1971. It has been hailed as the most significant law ever enacted to protect the employee in the work place. The act authorizes the Secretary of Labor to announce standards or rules for avoiding hazards and to inspect work places

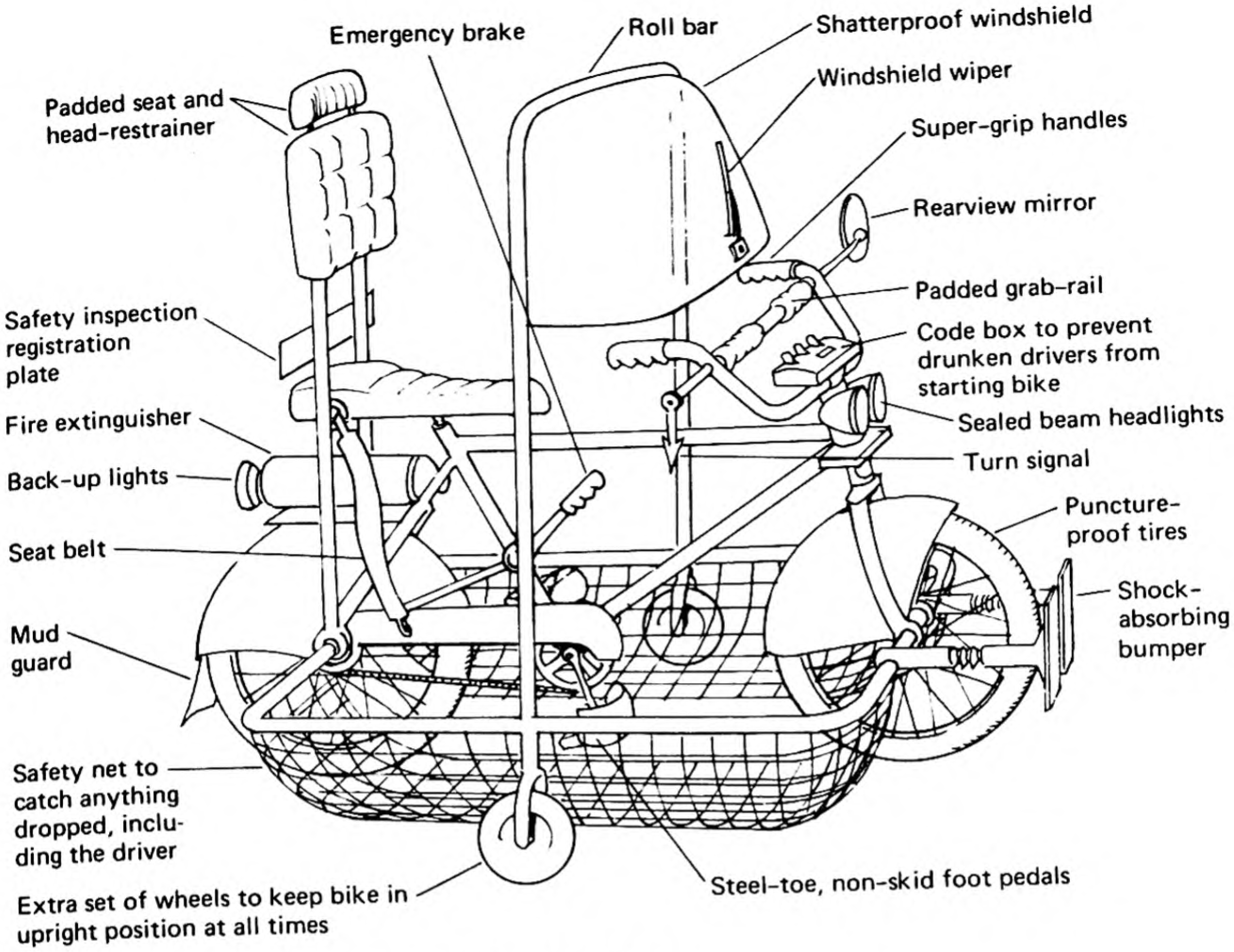

Emergency brake
Roll bar
Shatterproof windshield
Windshield wiper
Super-grip handles
Padded seat and head-restrainer
Rearview mirror
Padded grab-rail
Code box to prevent drunken drivers from starting bike
Safety inspection registration plate
Sealed beam headlights
Fire extinguisher
Turn signal
Back-up lights
Puncture-proof tires
Seat belt
Shock-absorbing bumper
Mud guard
Safety net to catch anything dropped, including the driver
Steel-toe, non-skid foot pedals
Extra set of wheels to keep bike in upright position at all times

*Fig. 7-7. "Safti-Cycle," the bicycle of the future.*

to determine compliance. It has been whimsically suggested that complete compliance to safety regulations might result in the design for bicycle travel shown in Figure 7-7.

### Causes of Injuries

After it is accepted that safety effort is legislatively necessary, economically sound, and emotionally satisfying, the next step is to determine what causes injuries. Two basic categories of hazards are unsafe acts by workers and unsafe working conditions. Exact examples of each category depend on the particular industry involved, but the general pattern is shared by all industries.

Dangerous work habits and careless practices are classified as *unsafe acts* when

- A smoker lights up in a nonsmoking area, and then blows up the area.
- Someone uses his finger instead of a brush to clean metal chips from a crevice in a lathe until he loses his finger.

- An operator watches the horseplay of another worker but continues to work with reduced concentration, until he is crippled.
- An operator removes his safety glasses because they are dirty and he cannot see his work clearly, and he never sees again.

Such behavior occurs everywhere. Most of the time nothing serious happens and a bad habit is formed. Because habits cannot be immediately corrected like an unsafe mechanical device, unsafe acts are difficult to overcome. Corrections require consistent attention by supervisors. Protective clothing such as hard-toe, nonskid shoes or tinted safety goggles may let an operator escape injury from some unsafe acts, but eventually he will be hurt unless he and his supervisor succeed in eliminating his faulty habits.

Injuries traced to physical and mechanical sources within the work environment are collectively attributed to *unsafe conditions*. Designers talk about a completely safe design, but there probably is no such thing. Someone will figure out a way to get hurt even though a machine is absolutely safe for all normal and most abnormal operations; an example is a table saw that required an operator simultaneously to push separated buttons with each hand before the blade could turn. Yet it failed to protect the operator's hand when he jammed a splinter into one button to allow him to adjust a piece of wood as it was being cut. While the perfect design may still be a dream, a manager can eliminate such unsafe conditions as

- Work places too cramped or crowded with unnecessary items
- Fire exits and escape routes not adequate in number or in marking
- Protective guards not attached or improperly installed
- Inadaquate illumination or work place subject to glare
- Protruding obstacles unmarked or electric wiring exposed
- Materials stacked too high or in the way of operations
- Warning signs torn down, unclear, or never erected

Many unsafe conditions are classified as "housekeeping" hazards. Good housekeeping naturally includes litter control and janitorial cleanliness. It should also be consistent. Maintaining near-constant conditions is safer, even if they are somewhat messy, because workers know where things are and can anticipate accordingly. Consistency also contributes to safe acts by making it easier to develop safe work habits that do not have to be changed very often.

### Prevention of Injuries

Accident prevention is a cycle of events. Training and workplace design are based on practices that have worked in the past. After safety procedures are installed, workers are urged to be safety-conscious. When an injury occurs, as inevitably happens, it is investigated to determine its cause, then the cycle is completed by redesigning work practices or the work place to avoid another accident of the same type.

An organization to promote safety interests may require a whole department or need just a committee, depending on the size of the enterprise and its needs. Any safety effort needs the support of top management, as well as the support of supervisors and workers, if it is to be as successful as possible. To initiate a program, a safety survey of plant conditions and accident history should be made by the safety staff or consultants. A reporting system and training procedures are developed as part of the total safety program according to the results of the survey.

Safety training for individuals should start with their first impression of the company and continue all through their employment. Job instructions should include safe work methods and stress the overall importance of safety. Continuous motivation to avoid accidents can be encouraged by showing films, posting humorous reminders, inserting safety news in a company paper, having competitions, and establishing a suggestion reward system. A good safety program requires considerable ingenuity because people do not like to think about injuries; a gruesome poster of a bloody, mangled body may just inspire an observer to look away or, even worse, to become so overly concerned that he has an accident from being too careful. And campaigns that emphasize how long each unit has gone without a lost-time accident sometimes backfire; once the period ends with an injury there may be a rash of additional injuries due to the letdown.

Accident and near-accident reporting is a vital part of injury prevention. The operation of a typical accident-reporting system is shown in Figure 7-8. Besides the obvious first priority of treating the injury, the reporting system assures accident investigation. The purpose of the study is to determine the causes to help prevent similar accidents. For this reason it is important to report "near misses" because they provide an opportunity to take corrective action before an actual injury.

A formal investigation produces a report that states the nature and causes of the accident; who was involved and the extent of the injury; the cost of medical and compensation expense, the damage to machines and materials, and the cost of lost time. Occasionally witnesses may deliberately withhold facts to avoid embarrassment or placing blame, but most people realize that compensation laws protect workmen regardless of who was at fault. The attitude found during an accident investigation is a good indicator of the success of a safety program.

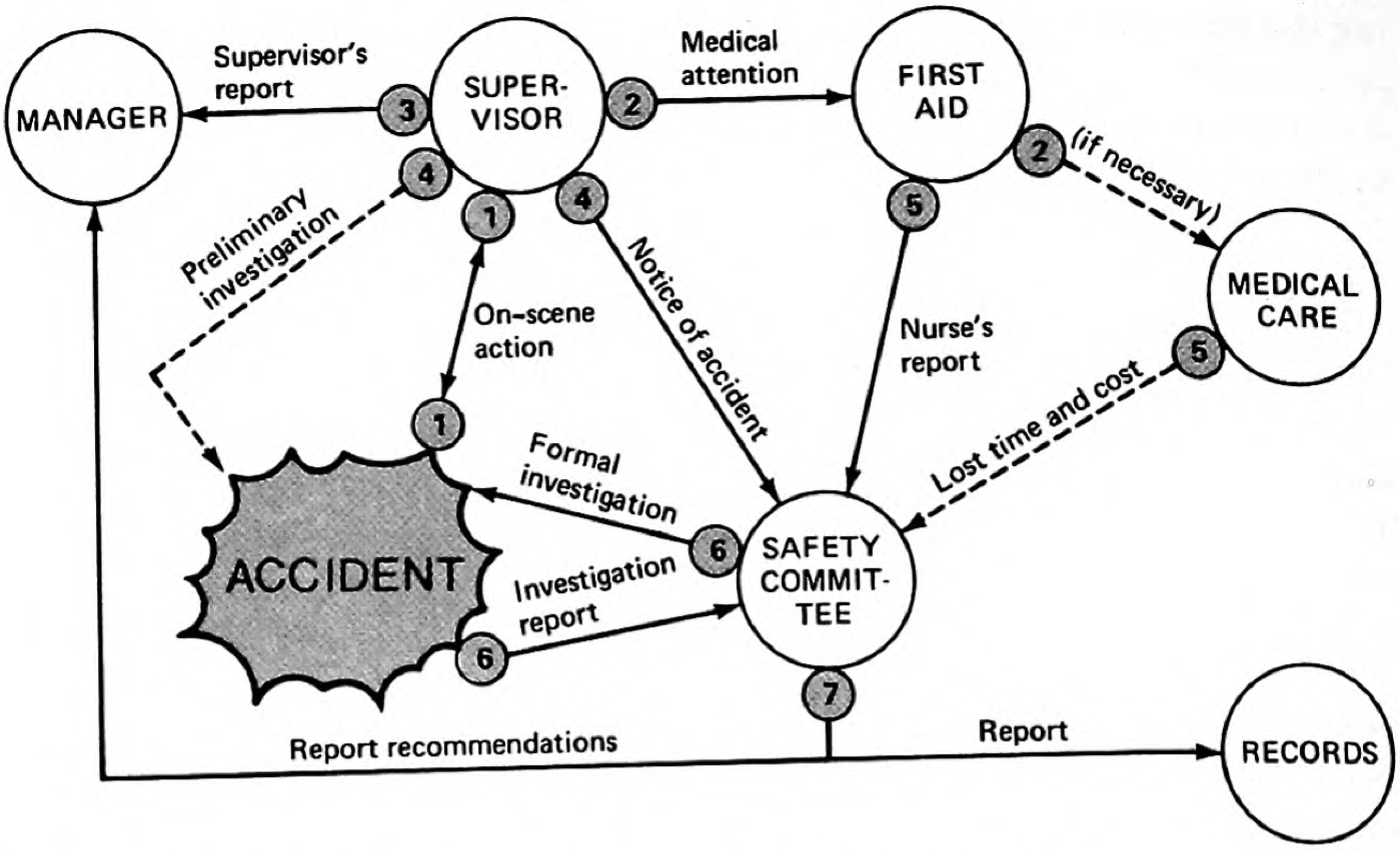

MANAGER
Supervisor's report
③
SUPER-VISOR
②
Medical attention
FIRST AID
②
(if necessary)
MEDICAL CARE
④
Preliminary investigation
①
④
Notice of accident
⑤
On-scene action
Nurse's report
⑤
Lost time and cost
①
Formal investigation
ACCIDENT
⑥
Investigation report
⑥
SAFETY COMMIT-TEE
⑦
Report recommendations
Report
RECORDS

*Fig. 7-8. Typical accident-reporting system showing the sequence of activities. The supervisor's immediate duty is to see that the injured worker receives prompt medical treatment, then to check the work place for leaks, fires, or other hazards in order to prevent further damage. Later, the supervisor will contact the safety committee or department and his immediate manager to prepare for a preliminary investigation. The formal investigation seeks to determine causes for the accident and steps that should be taken to prevent recurrence. The safety committee's concrete recommendations should meet the supervisor's approval, particularly if they involve a change in work methods or policies.*

Cooperation tends to indicate employee awareness of the prominence of accident prevention and to ensure employees that the employer is following fair practices in pursuing safety objectives. Injury prevention has to be a joint venture if it is to succeed.

## REFERENCES

1. Frank B. Gilbreth, *The Primer of Scientific Management*, D. Van Nostrand Company, Inc., Princeton, N.J., 1914.
2. A thorough treatment of motion-study principles and techniques is found in Ralph M. Barnes' *Motion and Time Study—Design and Measurement of Work*, 6th ed., John Wiley & Sons, Inc., New York, 1968.

# SECTION 3
# CONDUCT

Men can be stimulated by hope,
or driven by fear, but hope and
fear must be vivid and
immediate if they are to
be effective without
producing weariness.
BERTRAND RUSSELL
*Technique and Human Nature,* 1949

The best laid plans can be wasted by poor performance. Equivalently, a stirring performance may be squandered by poor planning. We have observed in previous sections the intricacies involved in developing a better way of doing things. In this section we will examine ways to improve the way things are done.

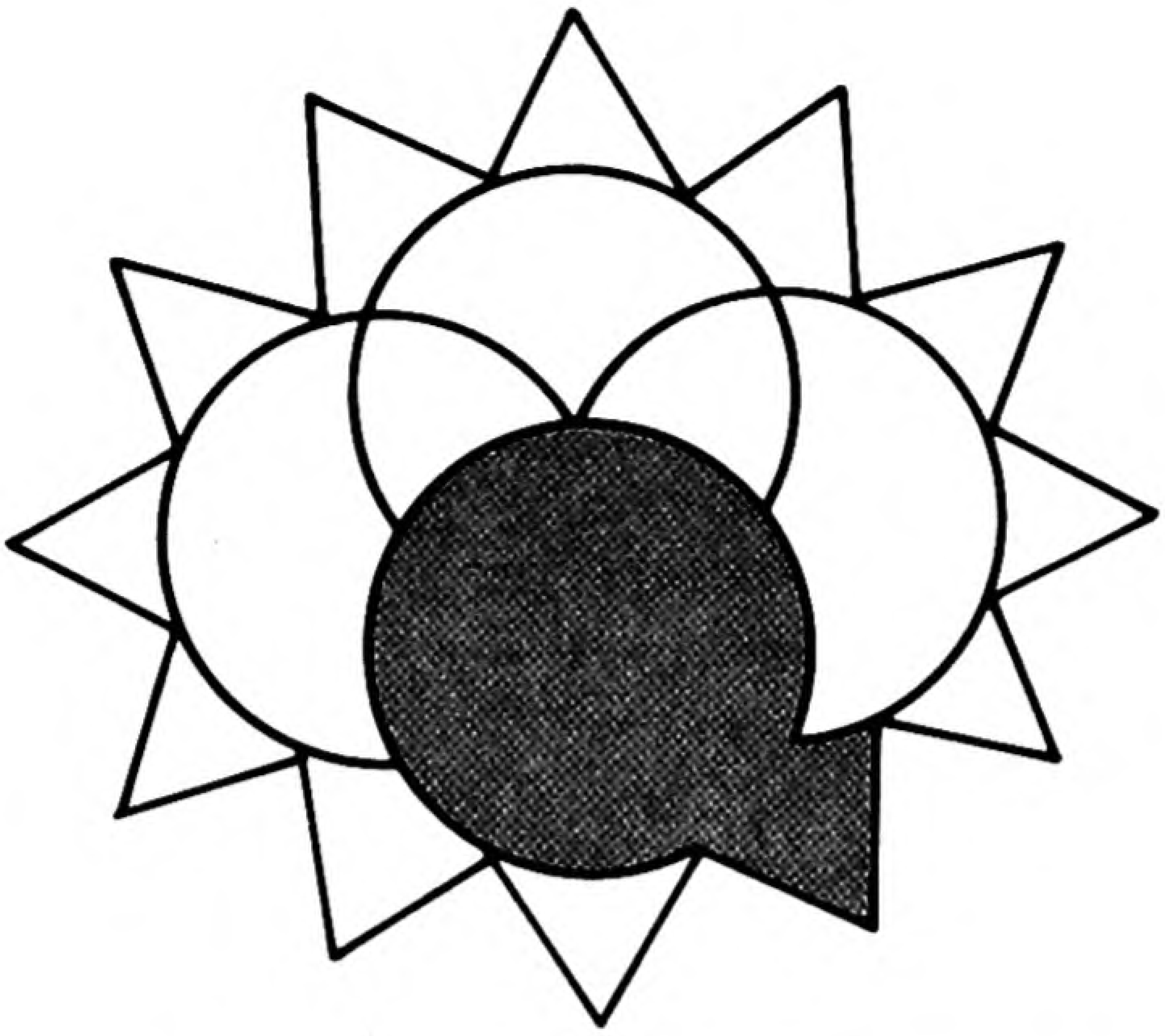
Place yourself in the position of a team manager. The team could be engaged in basketball, tiddly-winks, combat, business—anything. As the manager you have formulated the strategy for the next engagement. It is based on your knowledge of your team's capabilities, the other team's potential, and the conditions expected for the engagement. Now you have to arrange the operating details: make specific assignments, give detailed instructions, designate exact actions, and motivate the players. The sum effect of these efforts decides the quality of execution during the engagement, how the team works together.

Just as an orchestra conductor observes the musical score and leads the musicians while conducting a symphony, a manager assigns people and directs activities while conducting a project. Allocation of resources and arrangement of activities can be guided by different quantitative methods. The use of product indexes, resource grids, sequencing methods, assignment methods, and linear programming is described in Chapter 8, "Allocating."

The emphasis on quantitative methods in Chapter 8 switches in the next chapter to qualitative considerations of conduct. Managers can do much to make jobs rewarding and the work environment satisfying. The causes of human behavior are so complex that no one fully understands them, but several theories have been proposed. These theories and associated application techniques used to promote worker interest and to improve leadership are included in Chapter 9, "Motivating."

In addition to leading people, managers have to be concerned with the availability of resources. Cooperation is the key to teamwork but the success of a team's mission also depends on the nature of the group, situation, and sources of supply. Physical support for the mission flows through communication and material channels. Inventory and information management are emphasized in Chapter 10, "Coordinating."

# Chapter 8



# Allocating

**KEY SUBJECTS**

*The allocation function lies between a decision to follow a certain course of action and means taken to control the action.* The goal of allocating is to make the best possible use of limited resources. The effectiveness of allocations in meeting stated objectives affects significantly the amount of output for the given conditions.

*Many allocations are offhand judgments made according to experience and assisted by checklists or simple formulas.* Managers should allocate their own time to activities that most deserve attention and give only superficial regard to activities that are progressing well. Attention is called to problems by charts and reports that reveal when an activity's performance has reached a dangerous level.

*A sequencing problem occurs when a number of activities have to be performed in a specified order, with given performance standards and with known resources.* A resource grid is an example of an essentially intuitive approach that can be used for manpower leveling. Optimum-seeking procedures are available for some types of sequencing problems. The objective of these procedures is an arrangement which minimizes the time or cost of performing the sequential operations.

*The assignment method provides a set of directions which leads to an optimal match for each function or job and its associated resource.* A matrix is used to display how the function or job is related to the resource–hours required to produce a part on a machine, cost of service to a facility, etc. The entries in the matrix are altered by successive steps in accordance with the assignment procedures to reveal the pattern that best satisfies the requirements of the problem.

*Linear programming is the most famous allocation method.* It can be applied to very complex problems in a wide variety of situations. In an LP application all relationships are assumed to be linear. Explicit statements of the objective function and resource restrictions are necessary. When these conditions are met, linear programming can be used to determine the allocation of resources among competing uses that best meets the stated objective. A graphic solution method can be employed when there are no more than three uses for the resources. The Simplex method can accommodate a problem of any size. It provides directions to improve possible solutions successively until an optimal solution is recorded.

## CUTTING THE PIE

When a manager parcels out work assignments, he is performing an allocation function similar to a cook cutting pie. The cook knows how many pies he has and how many people he expects to serve. He wants to satisfy the eaters while not wasting any pie. The shape of the pie limits his slicing patterns, but he has the option to cut smaller pieces with the intention of allowing second helpings or to serve only once with a larger piece. He knows the richness, diameter, depth, and type of pie filling. These influence the piece size. In a comparable fashion, the manager works with known objectives, resources, and limitations in making allocations to perform a project.

The allocating function begins *after* the objectives have been decided, the resources committed, and the limitations identified. It *ends* with the designation of a preferred way to attain the objectives while conforming to the restricting resources and conditions. It does not include the initial decision to do a project nor control of the ongoing work. Consequently, allocating is just one of several steps in work management, but it is a significant one as illustrated by the following examples:

- A grant has been awarded to a university to establish an advising service for consumers. The amount of the grant and the available staff are known. The services which the university will provide have been set. To get started, the project director must distribute duties in order to offer the most services in the most needed areas.

- A log 30 feet long and 5 feet in diameter is approaching the head saw. The sawyer knows the demand for, and the profit from, different sizes of lumber that can be cut from the log. His objective is to saw the log into pieces that will gain the greatest profit for the company.
- A company has three warehouses for distribution of goods to retail outlets in the locality. At a given time each warehouse has its own different individual mix of stored items. Each retail outlet has orders of different sizes for the items. Thus, both supply and demand are known. Transportation costs from each warehouse to all retail stores are also known. The allocation problem is to determine which warehouse should fill which orders from the stores to minimize transportation costs.
- A machine shop has a steady stream of orders for customized work that can be done by different operators on different machines. Certain operators are more proficient on certain types of work, and certain machines are better suited to one type of operation than another. The dispatcher tries to assign the known orders to the man-machine team that can produce the orders most economically.

The relationship of the allocation process to other phases of work management is displayed in Figure 8-1. The allocation phase has received quite a bit of

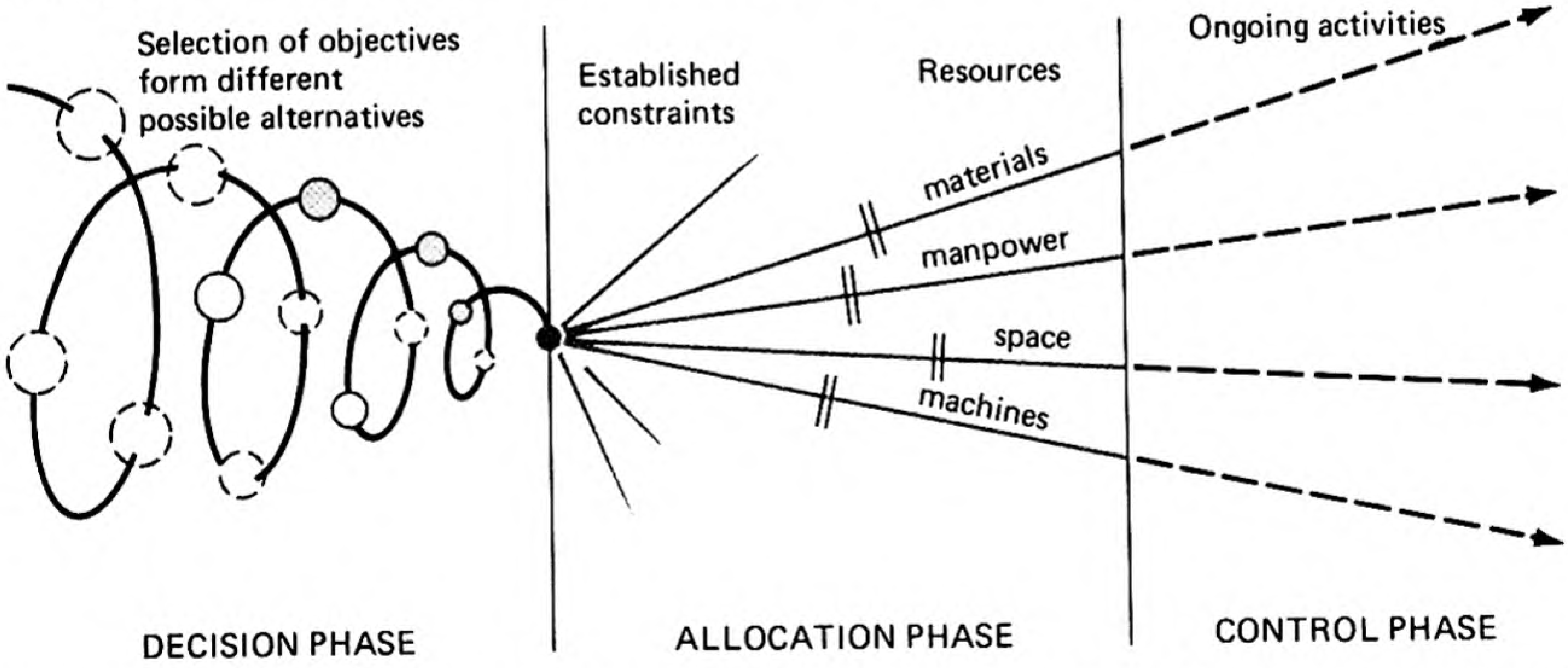


*Fig. 8-1. Relationship of allocation to decision making and control. A decision to pursue a certain course of action results from evaluating factors such as capabilities of the organization, expected reception by consumers, and profitability. The outgrowth of the decision is a statement of objectives. In order to implement the objectives, specific allocations are made from the resources available to the organization. The goal of the allocation process is to make the best possible use of limited resources. Given the objective to produce a certain product with known requirements to be sold at a given price, then the allocation process consigns materials from available stocks, men from the workforce, machine time from total capacity, space from existing facilities, etc. The effectiveness of the allocation significantly influences amount of output for the given conditions, hence total profit.*

attention because it is important and it is relatively easy to analyze; it is a *deterministic* problem, one where nearly all the influencing factors are known and can be stated in quantities. In contrast, both the selection of objectives and control phases involve properties which are difficult to assess, such as how to measure acceptance or social worth and how much faith to put in forecasts. While the allocation process is easy to analyze, a manager must remember that resource restrictions and limitations that are appropriate today may not be accurate tomorrow. It is easy to slip into the comfortable rut of continuing to apply the same allocation pattern just because it worked well in the past.

Most allocations are made on a rule-of-thumb or intuitive basis: when the work load reaches a certain level, hire part-time help—when a customer presses for fast service, work overtime—when a rush order arrives, get material from the nearest source regardless of price—when an important document has to be prepared, give it to Joe. Some allocations involve critical operations or substantial sums and deserve more attention. For these allocations many formal analysis techniques have been developed. In the following sections we will consider some informal methods that can help intuitive allocations, as well as some examples of mathematical procedures used to cope with complex allocation problems.

## INFORMAL ALLOCATION METHODS

Experienced managers have a "feel" for operations under their jurisdiction. Therefore, they make informal allocations from a mental file of capabilities and capacities. They have learned how much a given process can be overloaded and how long the overload can be sustained without inflicting damage. They have observed how workers react to different situations; so they seek to match operating assignments with compatible operators. They look ahead to anticipate future allocation requirements while making current assignments. Allocations so made are examples of the art of management because they are the result of a subtle synthesis of facts and opinions from many sources.

While many facets of intuitive allocations defy writing up, some guides will assist in making judgments. Checklists are often employed as reminders of combinations that have worked in the past. Simple formulas may be appropriate to assist in the distribution of resources. A formula suggested by value engineers to rate which studies should be conducted within the available study time is

$$\text{Study rating} = \frac{\text{potential savings}}{\text{study + implementation costs}} \times \text{probability of implementation}$$

The studies with the higher ratings are then carried out until the study time is exhausted.* Status reports of current conditions are vital for allocating resources in complex projects. They may be kept manually or by computer. A manager is simply guessing when he makes allocations without knowing what resources are actually available, whether or not they are still needed, and whether or not the original restrictions are still valid.

## ATTENDING TO EXCEPTIONS

A prime job of all managers is management of their own working time. A fundamental principle that promotes more effective use of time is *management by exception*—giving attention to the things that need it and not devoting attention to activities that are going well. This principle is great so long as the manager can identify accurately what is going well and what is or what may soon get into trouble. Here is the kind of report which reveals an "exception" that needs attention: sales in one region drop below a minimum level; cost in a department rises above a maximum allowable level; personnel turnover reaches a dangerous level; too many clerical errors are occurring; too much overtime is going on; too many complaints are coming from customers, etc. Such deviations outside preset limits are triggers for action.

The weakness of waiting for an indicator to signal trouble before giving it attention is that some loss has already been incurred or will unavoidably occur. This condition can be partially relieved by keeping track of key indicators on a chart. This historical pattern often provides an early indicator of coming trouble.

Figure 8-2 portrays the life cycle of a product. Several indicators are collected in one drawing to reveal any developing patterns or unusual relationships. The six indexes shown could be augmented or replaced with others more appropriate to the business. In practice, each index is appraised separately; but the final evaluation depends on the integrated effect. An experienced manager knows about what shape the curves should follow as a particular type of product becomes accepted in the marketplace after its introduction. He is concerned with both the absolute value of each indicator and its trend or rate of change with respect to the other indexes.

*Value analysis or value engineering is a relatively new discipline devoted to cost prevention by identifying the function of a product, establishing a value for that function, and developing means to provide value. The concept has been growing since the early 1940s. It is now recognized by a national organization called American Society for Value Engineering, aptly initialed SAVE. Many examples and guidelines for value analysis are given in the American Society for Tool and Manufacturing Engineers' *Value Engineering in Manufacturing,* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1967.

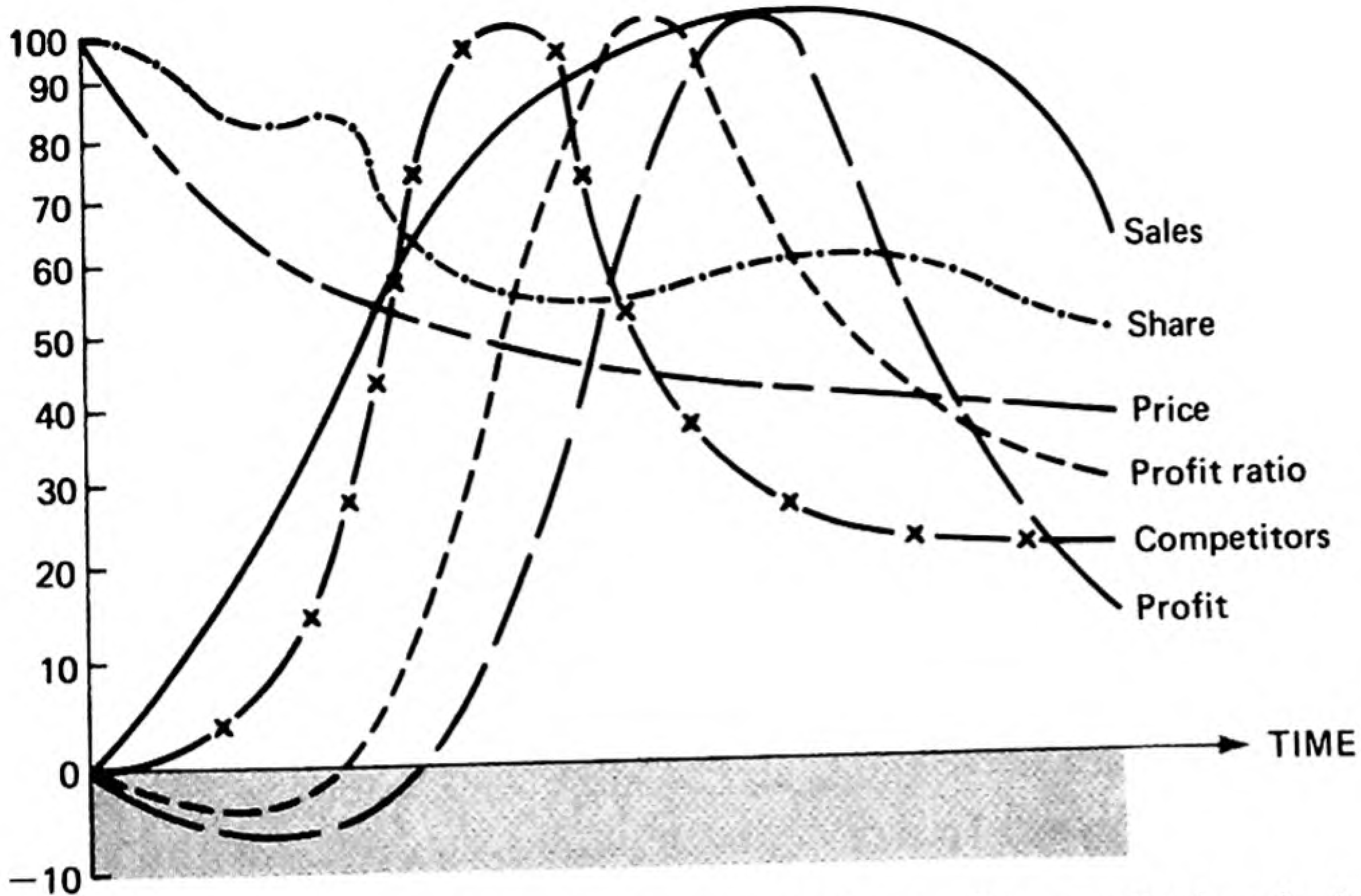


*Fig. 8-2. Life-cycle chart of product indexes. The vertical axis is scaled logarithmically according to the dimension of the index: number of units, percentage, dollars, etc. The horizontal scale is typically in months. The indexes shown in the figure are: sales volume (moving total of a 12-month span of sales); share of market* $\left(\frac{\text{sales volume}}{\text{total sales of all competing products}}\right)$*; price (unit price of the product, including rebates); profit ratio* $\left(\frac{\text{gross profit}}{\text{net sales}}\right)$*; competitors (number of directly competing products); and profit (net profit).*

## PUTTING THE PIECES TOGETHER

It is not always enough to know where attention should be centered and what things need to be done; interruptions and delays have to be expected. A "law" of nature conspicuous in management is "Murphy's First Law": "Whatever can go wrong, does." "Murphy's Second Law" stresses the compound nature of difficulties: "When one thing goes wrong, everything does." It would, of course, be absurd for a manager to sit around waiting for Murphy's curse to hit him; but he should anticipate that even his best allocations will sometimes run into snags. Allocations have to be reallocated when conditions change. Frequently it is just a matter of juggling assignments. On other occasions priorities may switch as new limitations or potentials arise. Then it is important to emphasize the sequencing aspect of allocation.

Figure 8-3 may appear at first glance to be a simple jigsaw puzzle. In some ways it is. But it also typifies a puzzle continually encountered by managers and supervisors. At the top of the figure is an arrow network representing a project to be performed. Each activity in the project is then represented by a rectangle. The dimensions of each rectangle are resources on the vertical axis and time

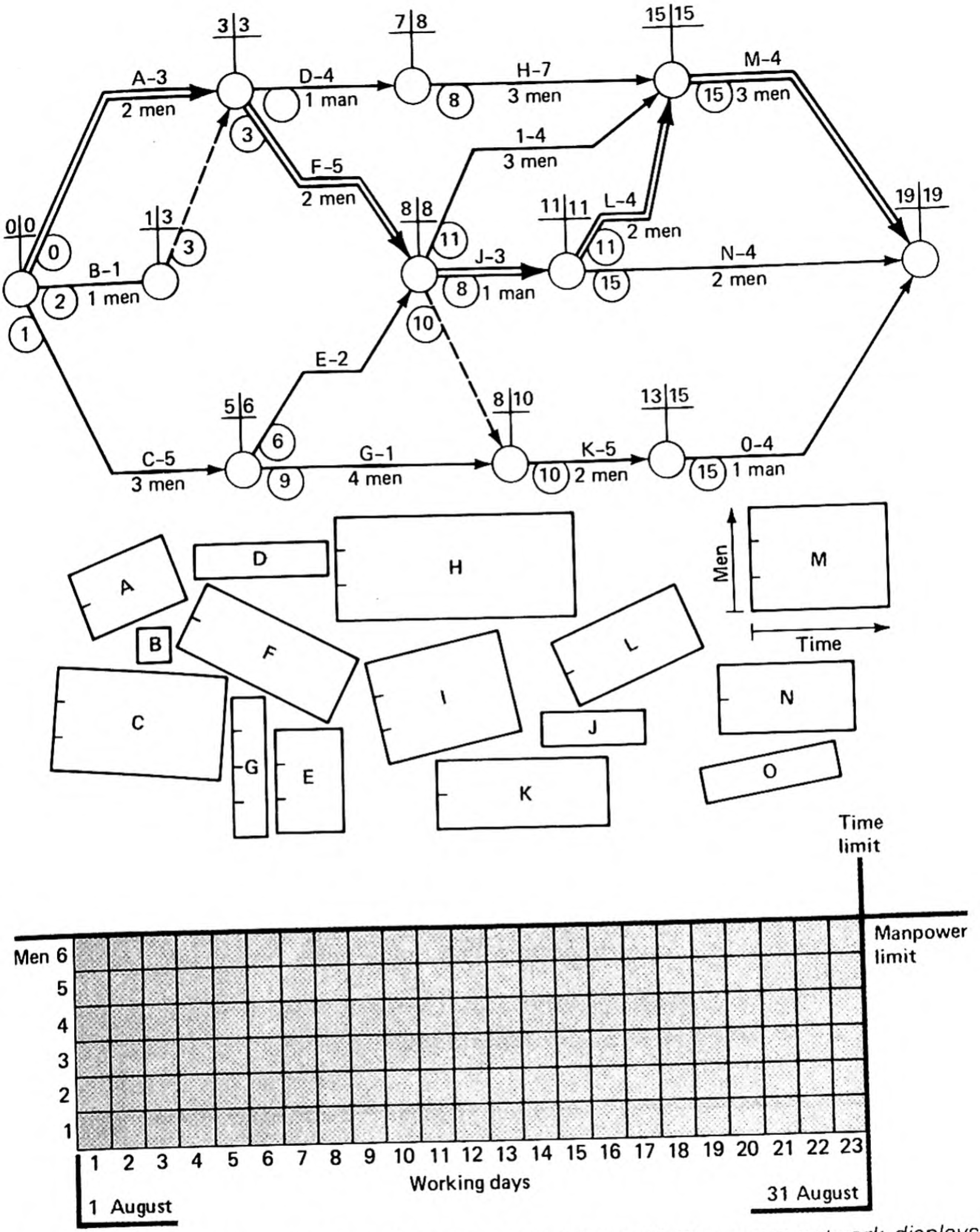

0|0
A-3
2 men
B-1
1 men
C-5
3 men
1|3
3|3
D-4
1 man
F-5
2 men
5|6
E-2
G-1
4 men
7|8
H-7
3 men
8|8
1-4
3 men
J-3
1 man
8|10
K-5
2 men
11|11
L-4
2 men
N-4
2 men
13|15
0-4
1 man
15|15
M-4
3 men
19|19
0
1
2
3
3
6
9
8
10
11
8
11
15
10
15
15
A
B
C
D
F
G
E
H
I
J
K
L
M
N
O
Men
Time
Time limit
Manpower limit
Men 6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Working days
1 August
31 August

*Fig. 8-3. Critical-path network and resource-restriction grid. The arrow network displays the activity description and time above each arrow with the manpower requirement below. It is implied that any man can work on any activity. If special skills were needed for certain activities, they would have to be so designated. Boundary times are given on the event crosses; the minimum project-completion time is 19 days. Each activity is represented by a men-days block based upon experience of the crew size most effective to perform the work involved in the activity. The vertical dimension of each block reflects the number of men needed to do the activity and the horizontal dimension is based on the activity's duration. The grid at the bottom sets the limiting conditions that only six men are available to work on the project and that it should be completed during the 23 working days of August.*

on the horizontal axis. As shown, the rectangles represent man-days; men on one axis and days on the other. The grid at the bottom establishes the time and resource constraints imposed on the project. The vertical resource scale is cut off at six men to show the maximum number of men allowed, and the time scale is dated to show the allowable duration. The allocation problem is to fit the man-day blocks into the constraint grid while conforming to the sequential restrictions given in the arrow network. Thus the jigsaw exemplifies the classic allocation puzzle: meeting the objective (getting the project done) with the resources available (manpower and time limits of the grid) while abiding by the given restrictions (sequence in which the activities must be done).

There are no specific rules or quick mathematical formulations available to allocate job assignments to certain men or to set the sequence of activities that conforms to the resource and time limitations. It is largely an intuitive exercise. To begin, a comparison of the 19-day earliest finish of the network and the 23 days allowed in the grid confirms that the time constraint is apparently reasonable. The remaining task is to fit the blocks into the grid. It can be done mentally or physically by maneuvering cutout rectangles. Therefore, the shape of individual rectangles cannot be altered without reevaluating the way an activity can be done. Experience has proved that there is one preferred man-day pattern for conducting each type of activity. Similarly, the sequence of activities given in the arrow network cannot be violated without serious consideration of its effect on the rest of the activities.

Figure 8-4 reveals one possible arrangement of the blocks within the grid. It allows one man to start two days late and two men to be switched to another project for the last six days. Note that after the allocations no float remains in the project; exact times for all starts and finishes have been designated. Also note

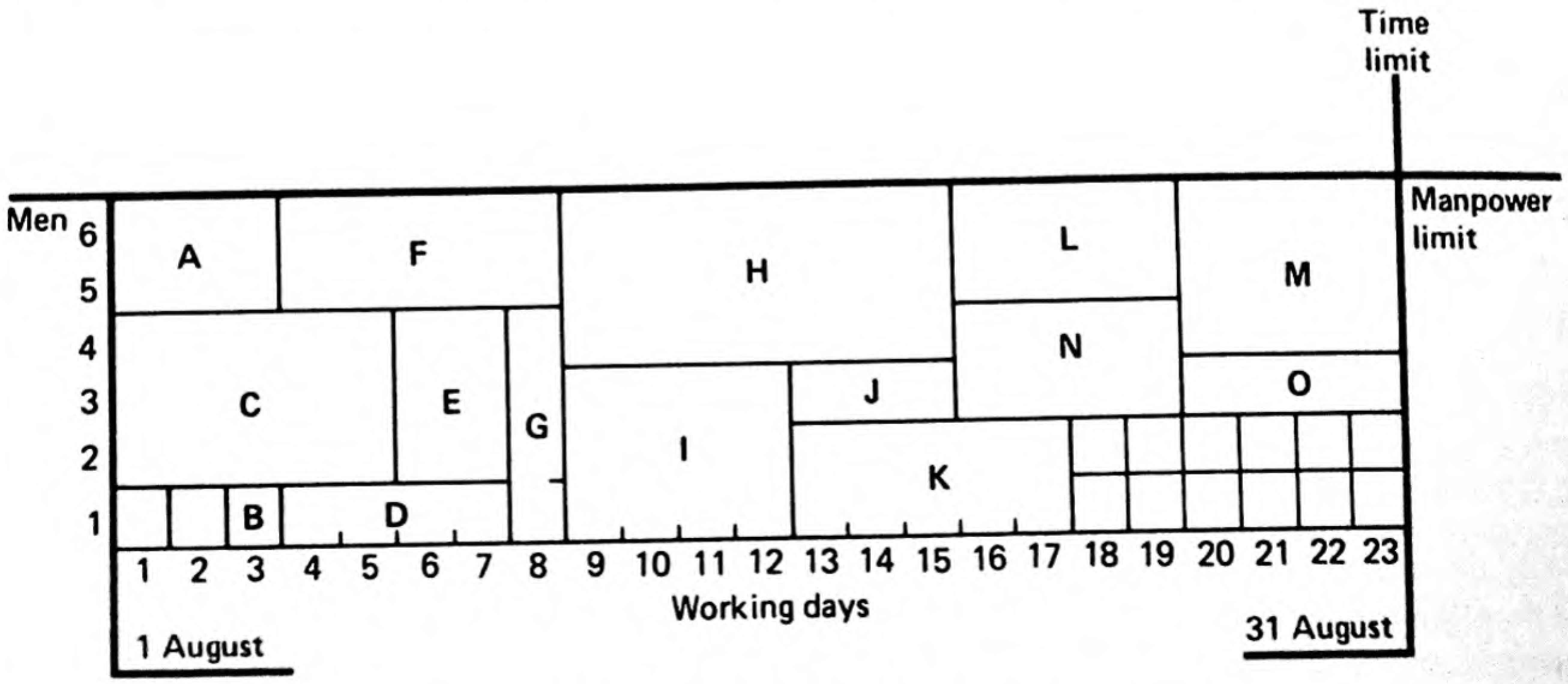


*Fig. 8-4. Resource grid completed for crew allocations to projects.*

that there is no way the project can be finished in the 19-day minimum suggested in the network when only a six-man crew is available.

The cut-and-try, trial-and-success method of allocation is very versatile, even though it can be frustrating. The example given in Figures 8-3 and 8-4 illustrates the concept of manpower leveling—smoothing the work load to avoid peaks and valleys for crew assignments. Leveling is important because it gets expensive to hire or assign a lot of men to a project for a few days, pull them off when the work load slackens, put them back on for another peak load, pull them off, and so on. In addition to smoothing out work cycles, grid allocations can also be used to assure maximum utilization of a key resource such as a crane or a one-of-a-kind production machine. In such cases, all activities relying on the key resource receive reserved space first and other activities are allocated in the remaining time. The resource grid is just a pictorial version of the mental framework needed to assign tasks in any resource-limited situation, and there are very few situations where resources are unlimited.

## OPTIMUM-SEEKING ALLOCATION METHODS

Although intuitive allocations are the mainstay of day-to-day operations, there are occasions when a refined search for the optimum allocation pattern is both feasible and expedient. The search is practicable if there are enough of the right kind of data to apply established optimum-seeking procedures. The application of these procedures usually requires specialized knowledge and considerable analysis expense. Therefore, the problem has to be worth solving because, occasionally, the cost of a better solution exceeds the value of attaining it. The search is expedient in recurring situations where the high cost of acquiring the best possible solution is repaid from repeated savings and from setting up or modifying a complex allocation system with a large financial impact.

Approaches used to obtain the best allocations run the gamut from rules for juggling numbers on scratch pads to elaborate computer programming. What they have in common is a guarantee that if the procedure is followed correctly it will produce an *optimal solution*—a solution that cannot be improved upon for the given conditions but may be equalled by other solutions for the same conditions. In the following sections we will explore three examples of formal allocation procedures. The first is a number-juggling exercise. The second uses a matrix to represent the allocation conditions. And the third is a graphic technique that introduces linear programming, the most famous allocation method. We are exploring these methods only to become aware of the available tools to assist the allocating function, rather than to become proficient in their use.

## SEQUENCING METHOD

A hint of the difficulties you can encounter in trying to sequence activities for best performance was evident in the leveling exercise shown in Figures 8-3 and 8-4. Now consider a situation in which there are five work stations (A, B, C, D, and E), and five different products have to pass through all five stations. Each product has a known time needed from each station and a set order for processing such as

- Product 1: A to B to C to D to E
- Product 2: B to E to D to C to A
- Product 3: E to D to C to B to A
- Product 4: C to A to D to E to B
- Product 5: D to B to A to D to C

The object is to select the sequence of products through the work stations that minimizes the total processing time. To get an idea of the magnitude of this problem, there are $(5!)^5$ or about 25 billion different possible sequences! A clerk could spend a lifetime just listing the combinations. Obviously, time-reducing procedures and computer assistance are essential. Many procedures and programs have been developed to make such problems more manageable, particularly in the area of assembly-line balancing.

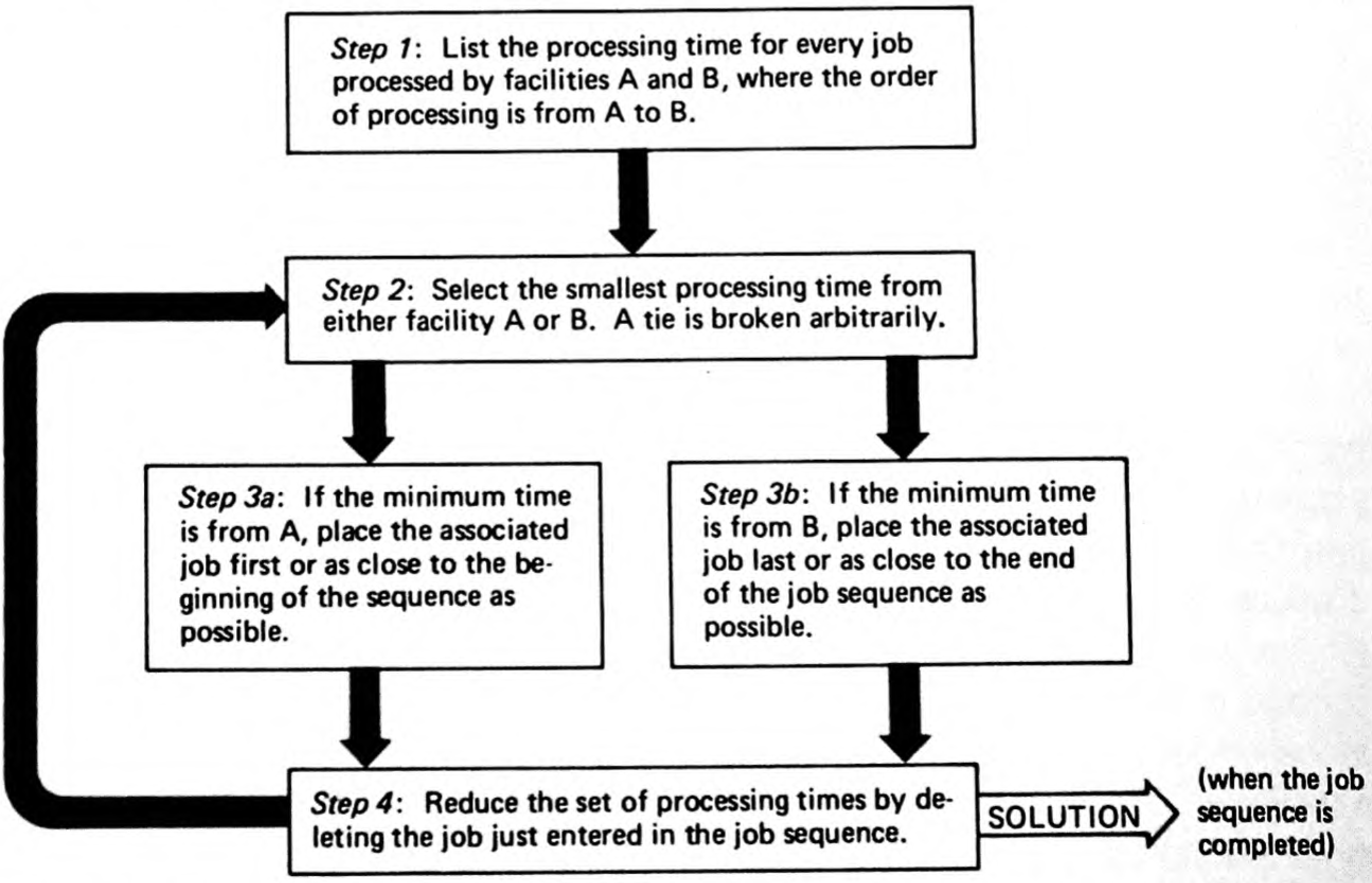

Step 1: List the processing time for every job processed by facilities A and B, where the order of processing is from A to B.
Step 2: Select the smallest processing time from either facility A or B. A tie is broken arbitrarily.
Step 3a: If the minimum time is from A, place the associated job first or as close to the beginning of the sequence as possible.
Step 3b: If the minimum time is from B, place the associated job last or as close to the end of the job sequence as possible.
Step 4: Reduce the set of processing times by deleting the job just entered in the job sequence.
SOLUTION
(when the job sequence is completed)

*Fig. 8-5. Flowchart for determining the sequence minimizing the time to process any number of jobs through two facilities.*

As an example of a rule to handle a relatively straightforward sequencing problem, consider the flowchart in Figure 8-5. The chart itself illustrates a convenient way to outline procedural steps; the arrows indicate the paths that might be necessary, depending on the composition of the problem, to yield a solution. The solution method described in the chart is appropriate only for sequencing activities in two facilities when the activities always pass from the first facility to the second. There can be any number of activities or jobs, but the processing times in each facility must be known and not be affected by the order in which the activities are sequenced. When these conditions are met, the procedure in Figure 8-5 yields the schedule that minimizes the elapsed time from the beginning of the first activity to the end of the last one.

An application of multiple jobs going through two facilities occurs when one department does the typing and artwork (T & A) for reports and another department prints and binds them (P & B). The time needed for report preparation depends mostly upon the content while the time to put the printed reports out depends on the number of copies to be made. Assume there are five reports to do (V, W, X, Y, and Z). The expected hours for processing each report in each facility are

| **REPORT** | **V** | **W** | **X** | **Y** | **Z** |
|---|---|---|---|---|---|
| T & A Dept. | 7 | 4 | 11 | 5 | 8 |
| P & B Dept. | 5 | 6 | 7 | 6 | 10 |

The steps in Figure 8-5 are followed below to discover the optimal sequence for processing reports.

The smallest processing time is four hours (step 2) in the first facility, so we enter report W as the first report to do (step 3*a*) and eliminate it from those left to consider (step 4).

| **REPORT SEQUENCE** | **REPORTS LEFT** | **V** | **X** | **Y** | **Z** |
|---|---|---|---|---|---|
| W ☐ ☐ ☐ ☐ | T & A Dept.<br>P & B Dept. | 7<br>5 | 11<br>7 | 5<br>6 | 8<br>10 |

The next smallest number is five and it occurs at two places, V and Y. We can use either one in the sequence because the choice will not affect the total minimum time (step 2). If we use report V (step 3*b*), it is placed last in the sequence as

| REPORT SEQUENCE | REPORTS LEFT | X | Y | Z |
|---|---|---|---|---|
| W ☐ ☐ ☐ V | T & A Dept. | 11 | 5 | 8 |
|  | P & B Dept. | 7 | 6 | 10 |

Now we continue cycling through the procedure steps spotting Y as the report with the smallest remaining processing time (6), and putting it next to W in the sequence. Then X has the smallest uncommitted processing time so we put it next to V. Finally, Z is inserted in the only remaining space to complete the order.

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| **OPTIMUM REPORT SEQUENCE:** | W | Y | Z | X | V |

If we had used report Y instead of V to break the tie for the second allocation, the final sequence would be unchanged. However, a tie breaker often switches the order of activities and thereby provides other optimal sequences with equal total elapsed time. The schedule for report preparation and printing is given by the bar chart in Figure 8-6. The total elapsed time for the five reports is 40 hours. Note that the only delays other than at the beginning or end are the one-hour gaps for the P & B department on both ends of report Z.

## ASSIGNMENT METHOD

Situations arise which call for the relatively permanent matching of a function or job to a resource: salesmen are appointed to sales territories; crews are assigned to travel given routes on planes or trains; ships are sent to specified berths; orders are allotted to different plants; and operators attend to assigned operations. The problem is to assign one function of each resource in an optimal pattern—one that minimizes or maximizes the total objective. Salesmen are matched to territories where their talents should maximize the total amount sold in all the territories combined. Crews are assigned to routes that collectively minimize travel and layover time spent by all the crewmen.

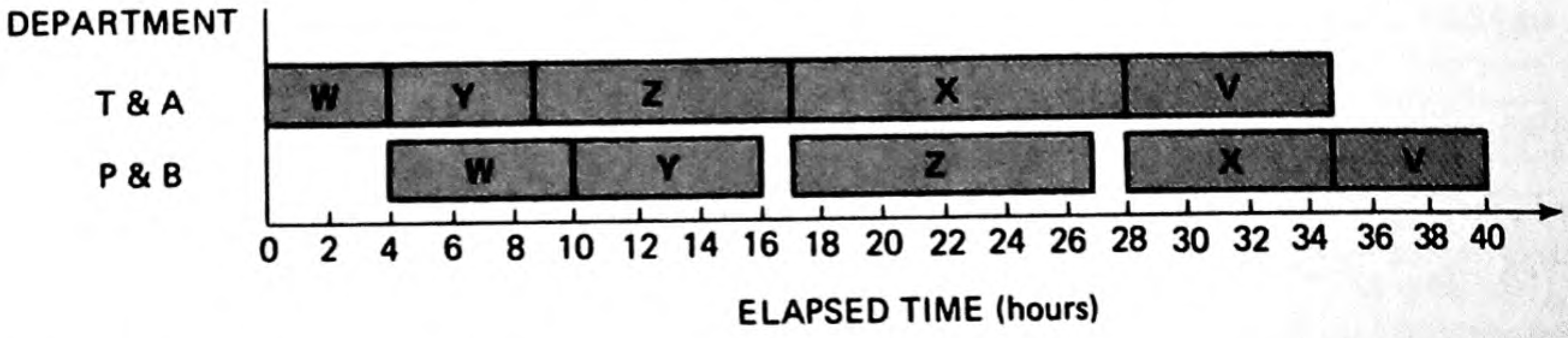


*Fig. 8-6. Bar chart for the minimum time sequence of five jobs passing through two facilities.*

The conditions under which each function can be done with any of the resources are conveniently displayed in a matrix. As represented in Table 8-1, three crewmen can be assigned to any of the three routes, but route assignments cannot be split. That is, one route is a complete assignment for each individual. Al is expected to have 114 minutes of travel time if he is assigned to route 1, 101 minutes for route 2, or 83 minutes on route 3. Since each crewman can be assigned to any route, the matrix will always be square—the number of rows equals the number of columns.

Table 8-1. MATRIX SHOWING TRAVEL TIME IN MINUTES FOR CREWMEN ON THREE DIFFERENT ROUTES

| | ROUTE | | |
|---|---|---|---|
| **Crewmen** | **1** | **2** | **3** |
| Al | 114 | 101 | 83 |
| Bob | 92 | 61 | 88 |
| Charlie | 74 | 81 | 99 |

With the data displayed so clearly, assuming they are accurate, it is easy to pick from the matrix the assignments that minimize total travel time: Al on route 3, Bob on route 2, and Charlie on route 1. This solution resulted from the natural visual action of picking out the smallest numbers in the rows and columns. In Table 8-2 we have mathematically conducted the same action by subtracting the smallest number in each row from all other numbers in the row (matrix A) and by subtracting the smallest number in each column from all other numbers in the column (matrix B). The result in this example is the same diagonal of zeros for both matrices. The remaining numbers in each matrix are *opportunity costs*—costs which result from not utilizing resources to the best advantage.

An opportunity cost turns into a real expense only when the better solution has been overlooked or ignored. For example, if Al had been assigned to route 2 instead of route 1, he would have had an extra 18 minutes of travel time on every trip, as shown in the first row (R1) and the second column (C2) of matrix A. The *job* opportunity cost for Bob had he been assigned to route 3 would be 27 minutes, the entry in R2, C3 in matrix A. Similar reasoning produces *route* opportunity costs in matrix B. If route 1 had been assigned to Al instead of Charlie, the route would have required 40 additional minutes of travel as shown by R1, C1 and matrix B. The subtractions performed to get the job and route opportunity costs ensure there is always at least one zero in each row and in each column. When there is a unique zero in each row and column as in Table 8-2, an optimal solution is recorded. When assignments do not fall out so conveniently, additional steps must be taken.

TABLE 8-2. OPPORTUNITY COSTS REVEALED BY ROW AND COLUMN SUBTRACTIONS PERFORMED SEPARATELY ON THE SAME 3 X 3 MATRIX

| Matrix A: | Row subtraction | | | Matrix B: | Column subtraction | | |
|---|---|---|---|---|---|---|---|
| | **Route 1 (C1)** | **Route 2 (C2)** | **Route 3 (C3)** | | **Route 1 (C1)** | **Route 2 (C2)** | **Route 3 (C3)** |
| Al (R1) | 31 | 18 | 0 | Al (R1) | 40 | 40 | 0 |
| Bob (R2) | 31 | 0 | 27 | Bob (R2) | 18 | 0 | 5 |
| Charlie (R3) | 0 | 7 | 25 | Charlie (R3) | 0 | 20 | 16 |

Operating costs for performing jobs A, B, C, and D on machines 1, 2, 3, and 4 are shown in matrix A of Figure 8-7. Row and column subtractions have been performed sequentially in matrices B and C, respectively. It makes no difference in the final answer whether row or column subtraction is done first. As given in matrix B, row subtraction was done first to yield all zero entries in column 1. This condition reveals that machine 1 is best suited for all the jobs, but since we must assign a job to each machine we cannot accept the solution. Column subtraction conducted on matrix B then produces zeros in matrix C for the other columns.

Knowing that we cannot improve upon a zero opportunity cost, it appears that there may be a solution available in matrix C. However, investigation discloses there is no way to get a unique zero assignment for every job and every machine from the present pattern. For instance, if job A was assigned to machine 3 and job B to machine 1, then there is no assignment left with a zero-opportunity cost for job C because the only machine with a zero in job C's row has already been assigned to job B.

Checking each individual assignment by itself becomes tedious for a large matrix. An easier tactic is to cover all the zeros with straight horizontal or vertical lines. If the minimum number of lines required is equal to the number of rows (or columns) in the matrix, a solution has been found. If the minimum number of lines is less than the dimensions of the matrix, additional steps must be taken to secure a solution. In Figure 8-7, only three lines are needed to cover all the zeros, confirming that we must continue the assignment procedure.

The lines drawn to cover the zeros as a check to see if a solution is available are the bases for modifying the matrix in a continued search for a solution. Lines are drawn in Figure 8-8, matrix D, to cover the zeros exposed in matrix C of Figure 8-7. Often the same minimum number of lines can be drawn in different rows and columns to cover all the zeros. It does not matter which pattern is chosen because all patterns will lead to the same solution.

MATRIX A: Costs for performing jobs on different machines

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 240 | 315 | 270 | 300 |
| B | 170 | 225 | 260 | 300 |
| C | 100 | 230 | 140 | 190 |
| D | 140 | 170 | 190 | 180 |

MATRIX B: Row subtraction

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 0 | 75 | 30 | 60 |
| B | 0 | 55 | 90 | 130 |
| C | 0 | 130 | 40 | 90 |
| D | 0 | 30 | 50 | 40 |

MATRIX C: Column subtraction

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 0 | 45 | 0 | 20 |
| B | 0 | 25 | 60 | 90 |
| C | 0 | 100 | 10 | 50 |
| D | 0 | 0 | 20 | 0 |

*Fig. 8-7. Original job-machine cost matrix and opportunity costs after initial row and column subtractions.*

Once the lines are in place, all the uncovered entries in the matrix are inspected to find the smallest number. This number is then added to the entry at each point the zero-covering lines intersect. The same number is subtracted from all uncovered numbers. The numbers covered by the lines with the exception of those at an intersection remain unchanged. This procedure is applied to matrix D to produce matrix E. The smallest uncovered number in matrix D is 10 at job C, machine 3. This number, 10, is added to the zeros in the column for machine 1 at jobs A and D, the line intersections. Then 10 is subtracted from each of the six uncovered numbers. The corrected matrix (matrix E) is now ready to be checked to determine if it provides a solution.

MATRIX D: Zero-covering lines drawn to check for a solution

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 0 | 45 | 0 | 20 |
| B | 0 | 25 | 60 | 90 |
| C | 0 | 100 | 10 | 50 |
| D | 0 | 0 | 20 | 0 |

MATRIX E: Smallest uncovered entry added to line intersections and subtracted from all uncovered numbers

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 10 | 45 | 0 | 20 |
| B | 0 | 15 | 50 | 80 |
| C | 0 | 90 | 0 | 40 |
| D | 10 | 0 | 20 | 0 |

MATRIX F: Zero-covering lines drawn to check the corrected matrix for a solution

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 10 | 45 | 0 | 20 |
| B | 0 | 15 | 50 | 80 |
| C | 0 | 90 | 0 | 40 |
| D | 10 | 0 | 20 | 0 |

*Fig. 8-8. Assignment procedures for checking the matrix to see if a solution has been obtained and for correcting the matrix when the problem is unsolved.*

Again lines are drawn to cover all the zeros. The locations of the lines have changed as shown in matrix F, but still only three lines are required. Therefore, a solution is not yet available. A visual check confirms the lack of a solution by showing that if jobs A and B are assigned, respectively, to machine 3 and 1, no zero-opportunity cost assignment is available for job C.

A second round of correcting and checking begins by locating the newly smallest uncovered number, 15 in row 2, column 2. By adding 15 to the zero-covering line intersections and subtracting 15 from the uncovered numbers, we obtain the second corrected matrix shown in Figure 8-9, matrix G.

There is no way to cover all the zeros in matrix G with less than four lines. Thus a solution is available. The final step is to identify unique zero-opportunity cost assignments. Wherever there is only one zero in a row or column, an assignment is specified. As shown in matrix H, job A can be done only by machine 3 if it is to have a zero-opportunity cost. Similarly, machine 4 has a zero-opportunity cost only for job D. From the remaining possible allocations (job B or C to machine 1 or 2) the zeros indicate job C to machine 1 and job B to machine 2.

**MATRIX G:** Second correction based on matrix F

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 10 | 30 | 0 | 5 |
| B | 0 | 0 | 50 | 65 |
| C | 0 | 75 | 0 | 25 |
| D | 25 | 0 | 35 | 0 |

**MATRIX H:** Assignments made after checking matrix G to determine that all the zeros could not be covered with less than four lines

| | MACHINE | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| JOB A | 10 | 30 | 0 | 5 |
| B | 0 | 0 | 50 | 65 |
| C | 0 | 75 | 0 | 25 |
| D | 25 | 0 | 35 | 0 |
| COST | $100 | $225 | $270 | $180 |

*Fig. 8-9. Second correction and final determination of the job-machine assignments for minimum total cost.*

In our example there is only one minimum-cost allocation pattern. No other combination of assignments can produce a lower total cost than

| ASSIGNMENT | COST |
|---|---:|
| Job A to Machine 3 | $270 |
| Job B to Machine 2 | 225 |
| Job C to Machine 1 | 100 |
| Job D to Machine 4 | 180 |
| Total Cost | $775 |

A condition where there is more than one optimal assignment pattern would be indicated by at least a pair of activities having zero-opportunity costs for the same pair of resources:

| | MACHINE | | |
|---|---|---|---|
| | 1 | 2 | |
| Job X | 0 | 0 | Opportunity costs |
| Job Y | 0 | 0 | |

Then job assignments can be given to either machine without increasing the minimum total cost.

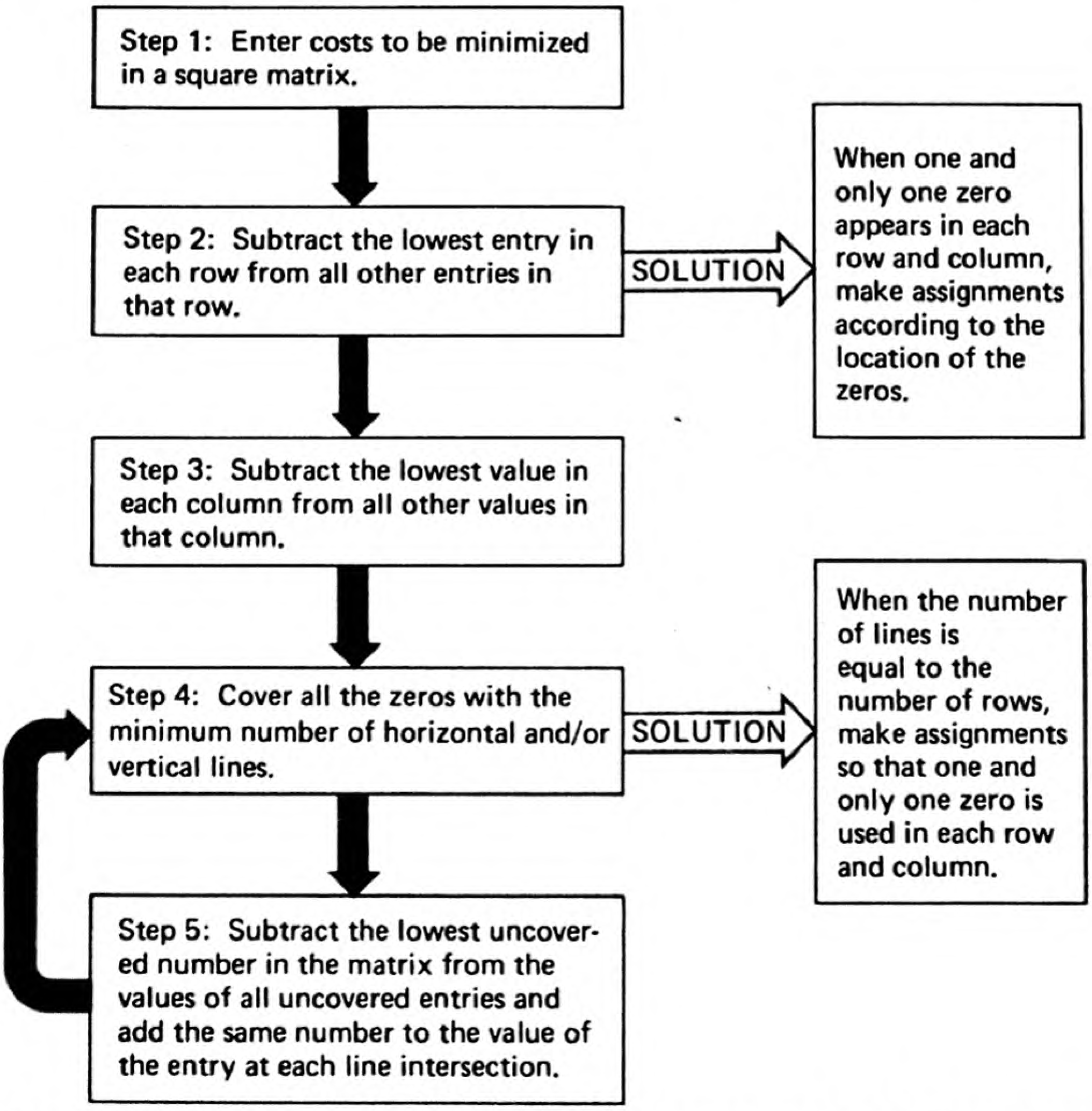

Step 1: Enter costs to be minimized in a square matrix.
Step 2: Subtract the lowest entry in each row from all other entries in that row.
SOLUTION
When one and only one zero appears in each row and column, make assignments according to the location of the zeros.
Step 3: Subtract the lowest value in each column from all other values in that column.
Step 4: Cover all the zeros with the minimum number of horizontal and/or vertical lines.
SOLUTION
When the number of lines is equal to the number of rows, make assignments so that one and only one zero is used in each row and column.
Step 5: Subtract the lowest uncovered number in the matrix from the values of all uncovered entries and add the same number to the value of the entry at each line intersection.

*Fig. 8-10. Flowchart for applying the assignment method. Steps 4 and 5 repeatedly correct the matrix entries until a solution is secured.*

A flowchart that summarizes the assignment procedures is given in Figure 8-10. It would not have been too difficult to obtain the solution for the 4-by-4 example problem by inspection or just by trying out all possible solutions; there are 4! = 24 possible combinations. But consider a 10-by-10 matrix where there are about three and a half million possible combinations. Then an *algorithm* (a mathematical term meaning a systemized procedure for determining a solution) is not a luxury, it is indispensable.

With a little practice the assignment method is remarkably easy to apply; typically an algorithm is more difficult to describe than it is to use. Slight modifications of the assignment algorithm greatly increase its versatility. It can be used to find a maximized allocation pattern (say, you want to maximize profit instead of minimizing cost as in our example) by initially subtracting all entries in the matrix from the largest number entered. In effect, this process converts all values to "relative costs" and allows application of the minimization procedures in Figure 8-10. If a certain function-resource matching is impossible or unwieldy (say, one machine is not equipped to do a certain job), such an assignment can be blocked by entering a very large cost for the match-up. If there is one extra function or resource and the intent is to find which one should not receive an allocation, a dummy function or resource is added to keep the matrix square, and zeros are entered for all the dummy's costs. The result is that an assignment is forced on the dummy and the actual function or resource associated with the assignment is left out of the final allocation pattern (see Problem 4c, *Student Involvement Guide*, as an example).

## LINEAR PROGRAMMING METHOD

Linear programming, usually called *LP* in conversation, is one of the most renowned tools of management science. Since its introduction in 1947 by George B. Dantzig, it has been extensively applied to a great variety of allocation problems. Dantzig's contribution, named the *Simplex* method, took much of the labor and guesswork out of allocating, and encouraged the search for optimal solutions in complex situations. Acceptance of the Simplex method was hastened by the availability of computers to perform the repetitious routines by which the Simplex algorithm seeks out an optimal solution.

The assignment method we observed in the previous section is a variant of linear programming where adequate resources are ready to meet demand, and the allocation is simply designed to match the supply with the demand. In general, linear programming is applied to problems where resources are limited and alternative functions compete for their use. The word "linear" imposes the restriction that all relationships in the problem are assumed to be proportional. For instance, a 10 percent change in one variable results in a 10 percent change in related variables. The linear limitation can be overcome by resorting to other techniques, one of which is called nonlinear programming, but the accuracy obtainable using linear relationships is sufficient for most management applications.

### LP Fundamentals

We will not attempt to go into the workings of the Simplex method and its variations; it is too long for our purposes here. Instead we will get acquainted with the terminology and concepts to recognize the types of problems that can be solved with LP and the characteristics of the LP solution method. Although most practical LP problems include too many variables for a graphic solution, we will follow a graphic development of a solution to clarify the procedures involved.

Figure 8-11 is a graph of the equation $X + 2Y = 90$. Every point on the line representing the equation is a combination of $X$ and $Y$ that totals 90. Where the line touches the $x$ axis the mix is 90 of $X$ and 0 of $Y$. Conversely, on the $y$ axis the equation has values of $0 + 2\ (45) = 90$. Between these end points are many other solutions to the equation. All the points under the line between the two axes add up to some value less than 90. This condition is described by an *inequation*— a mathematical statement that a total is "less than or equal to ($\leq$)" a certain value, or that the total is "greater than or equal to ($\geq$)" a given value. In Figure 8-11 the shaded area represents combinations of $X$ plus $2Y$ with totals less than or equal to 90, $X + 2Y \leq 90$. An inequation expresses

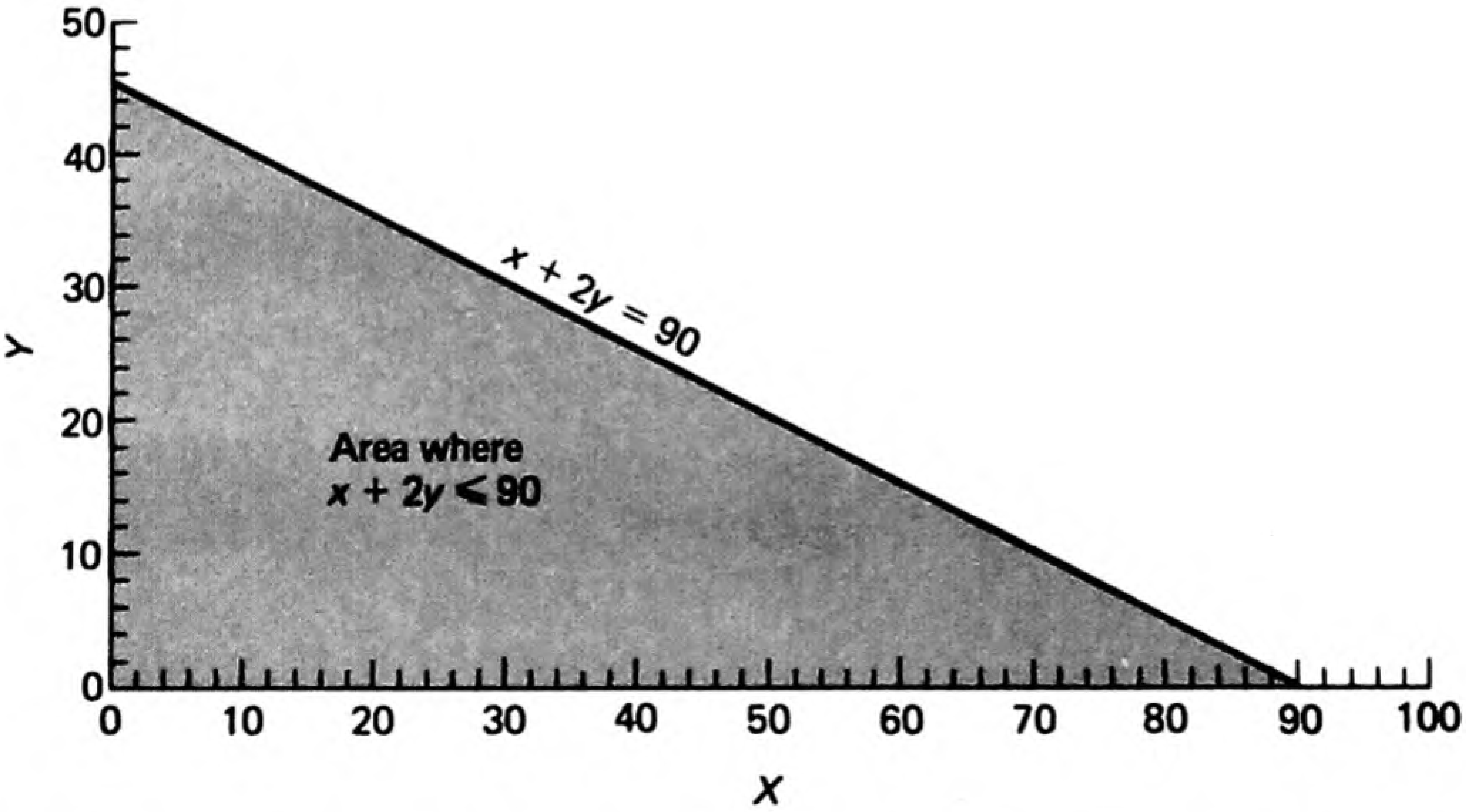


*Fig. 8-11. Graph of the line satisfying the equation $X + 2Y = 90$ and of the area satisfying the inequation $X + 2Y \leq 90$.*

mathematically a condition we describe in conversation when we say: "Buy any two of them but don't spend more than 10 dollars," or "Take either kind you want but be sure to get at least three bags full." Statements of inequalities occur in linear programming because demands ($X$ and $Y$) are competing for resources (90 units of something), and what $X$ is allocated, $Y$ cannot have. When you give the terms physical meaning, the inequation and its graph are easier to understand. Suppose X and Y are two different products and both products must pass through the packaging department where one unit of X takes one minute to package and one unit of product Y takes two minutes. Only 90 minutes are available in the packaging to work on either or both products. Thus, at most, 90 units of product X could be packaged if product Y was left out, 45 units of Y with no units of X, or some combination such as 30 units of both X and Y. Further, if less than the maximum allowable of X and Y is sent to the packaging department, it is assumed that the released time would be used to package other products.

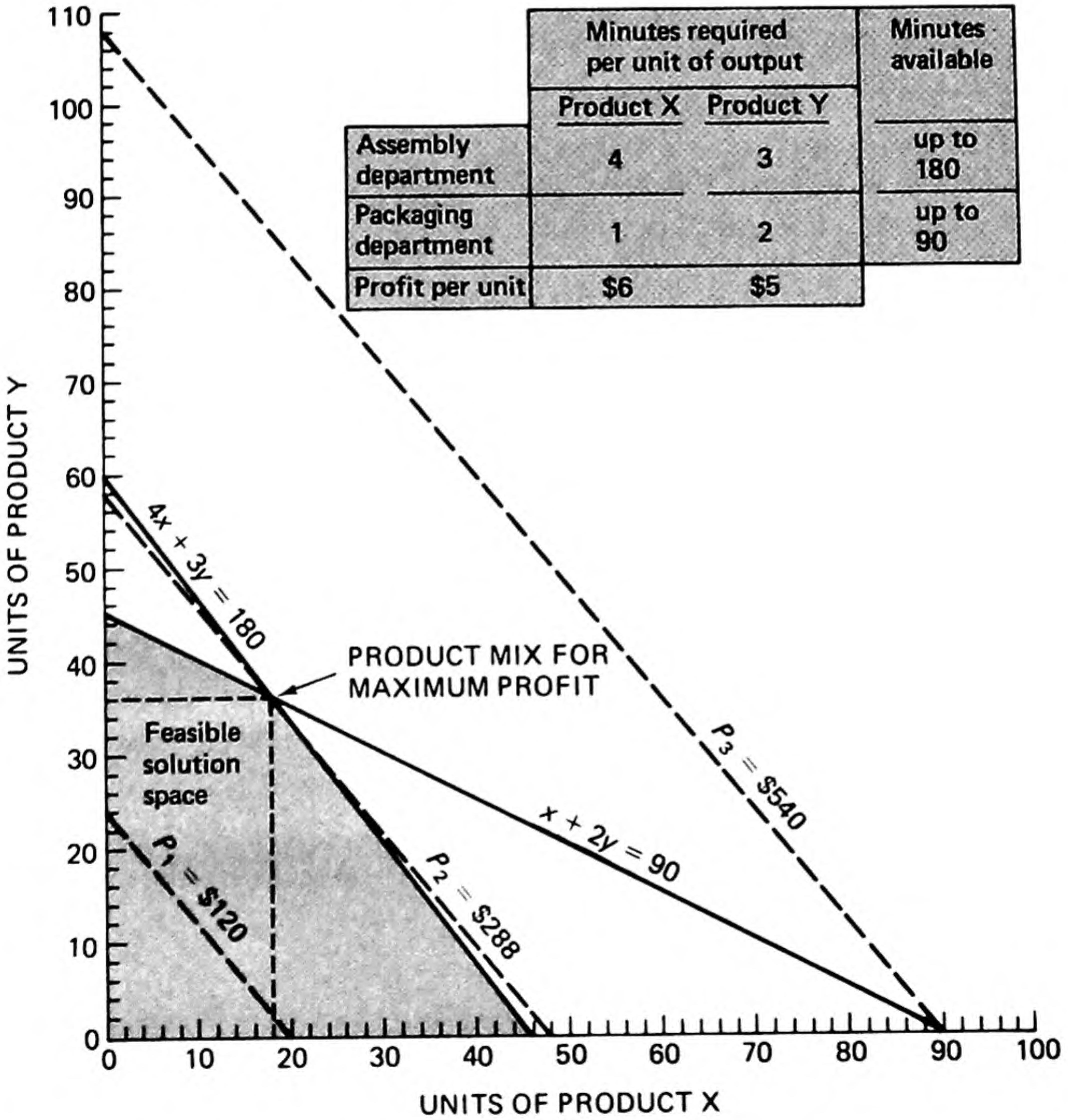
The shaded area of the graph in Figure 8-11 represents all "feasible solutions" to the inequation. The feasible solution space accounts for all combinations of X and Y requiring from 0 to 90 minutes in packaging. The limits of the shaded area also imply the physically obvious condition that there is no negative unit of X or Y. Mathematically, the non-negative condition is stated as $X > 0$ and $Y > 0$, and it completes the description of boundary conditions for the graph $X + 2Y \leq 90$.

Two additions are made to Figure 8-11 to produce the graph in Figure 8-12. Another inequation, $4X + 3Y \leq 180$, represents an additional resource restriction: product X requires four minutes to assemble, product Y requires three minutes, and at most 180 minutes are available in the assembly department. Since both products must abide by restrictions from both the packaging and assembly departments, the previous feasible solution space is reduced to the shaded area shown. The other condition added in Figure 8-12 is a representation of the *objective function*—a statement of the objective to be maximized or minimized in the solution of a problem. For products X and Y the objective is to maximize profit. The objective function is then a statement of how X and Y contribute to profit. The equation, $P = \$6X + \$5Y$, is read: Profit equals $6 multiplied by the number of product X produced plus $5 multiplied by the number of product Y produced.

Three lines that satisfy the profit equation are shown in Figure 8-12. The solution to an LP problem depends on selecting the optimal mix which maximizes the objective function while adhering to the restrictions imposed by the inequations. In our graphic example, the most profitable mix of products X and Y is identified by a line representing the largest possible profit that is inside the feasible solution space. Line $P_1 = \$120$ is inside the feasible solution area but it does not show a very large profit. Line $P_3 = \$540$ shows a very large profit but is not a feasible solution. Line $P_2 = \$288$ represents the highest attainable profit that conforms to the restrictions in the assembling and packaging departments. Where it just touches the feasible solution space designates graphically the optimal product mix: $X = 18$, $Y = 36$, and $P = \$6(18) + \$5(36) = \$288$.

### LP Applications

The concepts explored in the graphic treatment of resource allocations are also the foundations for the Simplex method. The graphic method is severely



| | Minutes required per unit of output | | Minutes available |
|---|---|---|---|
| | **Product X** | **Product Y** | |
| **Assembly department** | 4 | 3 | up to 180 |
| **Packaging department** | 1 | 2 | up to 90 |
| **Profit per unit** | $6 | $5 | |

*Fig. 8-12. Graphical display of LP problem restrictions and objective function. Limiting conditions and unit profits are shown in the table. The shaded area represents all the feasible combinations of products X and Y that can be produced while abiding by the restrictions. Dashed lines represent three profit levels obtainable from different product mixes. $P^2$ is the largest profit possible from a feasible mix; it touches the feasible solution space at the point $X = 18$ and $Y = 36$.*

limited for practical applications because there are at most only three axes available to represent products or functions. The Simplex method can accommodate any number of functions and resources as long as the problem can be formulated in linear relationships with explicit statements of the objective and constraints.

The procedure followed in the Simplex method is to find an initial solution which satisfies all the constraints. Then additional specified steps are followed to modify the initial solution by making adjustments that better fulfill the problem objective. This process of examining and correcting the current solution in search of a better one continues until the rules outlined in the Simplex algorithm reveal that no further improvements are possible. These essentially mechanical repetitions can be conducted by hand, but easy access to computers and standard LP computer programs has made manual LP computations generally uneconomical.

Most organizations have allocation problems that can be treated successfully by linear programming methods. A few typical problems are discussed below.

- An advertising manager has an annual advertising budget to place with different media to achieve the greatest possible exposure for his products. He has several products and several means of advertising which compete for allocations from his limited budget.
- A manufacturing firm distributes products from its factories to its warehouses. The problem is to decide how many products of which types should be stored in each warehouse to minimize the production and transportation costs. Additional complications could include consideration of the distribution costs from the warehouse to retailers as part of the total production-warehousing-marketing expense.
- Plant layout design and plant location questions involve the allocation of production capacity to meet internal coordination requirements and external market demands.
- Long-range planning becomes an allocation problem when planners assume a set of future conditions are certain to occur and then evaluate how resources can best be used under the given conditions. A typical problem is the assignment of capital resources to revenue-producing investments that would produce the highest rate of return on the amount invested. The returns obtainable from the optimal investment pattern from each set of conditions are then analyzed with respect to the relative likelihood that the conditions will actually occur.
- Blending problems occur in mixing such products as crude oils, paints, molten metals, chemicals, and grain. The objective is to get the minimum-cost mix that meets certain standards for contents when the ingredients of the mix are of different proportions.

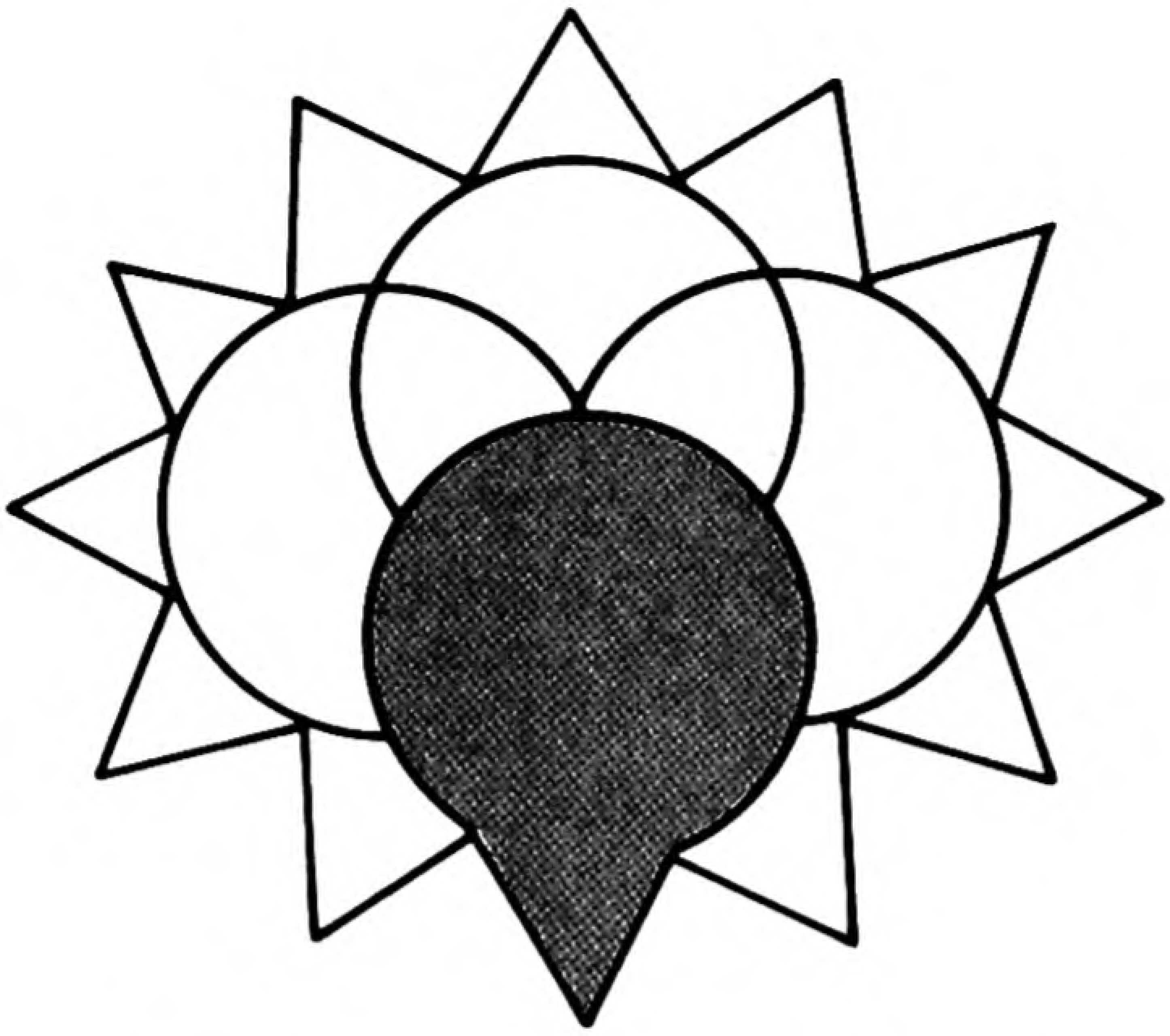
- Product-mix problems are among the most cited applications of linear programming. They include the whole spectrum of situations in which production facilities can be used to produce different products and each product has it own cost, revenue, and market expectation. The objective is to allocate the available production capacity to the most profitable products.

The importance of linear programming is summed up nicely by Harvey M. Wagner: "Unquestionably, linear optimization models are among the most commercially successful applications of operations research; in fact, there is considerable evidence that they rank highest in economic impact."[1]

## REFERENCE

1. Harvey M. Wagner, *Principles of Operations Research with Applications to Managerial Decisions,* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1969, p. 33.

# Chapter 9



# Motivating

**KEY SUBJECTS**

*Management now recognizes motivation as a major responsibility.* Money is no longer the exclusive motivator it was previously believed to be. The behavioral approach to work incentives is (1) to make the job itself so interesting that it becomes its own reward and (2) to create an environment in which employees find opportunities for personal growth and satisfaction.

*Human behavior is thought to be directed by needs an individual seeks to satisfy and goals he acts upon.* A need creates a tension. A goal is identified to relieve the tension. Actions are initiated to achieve the goal and, if successful, the original need is satisfied. Then another need emerges. A need with a high expectation of achievement is generally more motivating than one with only a remote chance of being satisfied. Managers can use need and goal theory by assisting workers to recognize which actions in the work environment contribute to goal satisfaction.

*Theories proposed to explain employee behavior and to guide job design include McGregor's Theory X and Theory Y, Maslow's hierarchy of needs, and Herzberg's two-factor theory of motivation.* Maslow suggests that as each lower-level need is satisfied, the next higher level of needs becomes the source of motivation. In Herzberg's concept, there are factors in the work environment that act only as dissatisfiers if not appeased, and there are job conditions that increase motivation if satisfied but do not lead to discontent if not satisfied. All the theories have advocates and detractors.

*Several motivational techniques have been designed and applied to improve work performance.* Job enrichment attempts to match job-skill requirements with work-skill capabilities. Leadership programs may utilize a managerial grid which examines the degree to which a manager is production-oriented and people-oriented. In sensitivity training, participants are assigned to T groups where they engage in frank, unstructured discussions intended to increase their sensitivity to themselves and to others. *Management by objectives* (MBO) is a widely used procedure in which superiors and subordinates first meet to set mutually agreed-upon goals, and then meet periodically to evaluate progress in attaining goals.

*No single theory of motivation or method of motivating workers has been unanimously endorsed.* Each theory and practice has its own strengths and weaknesses. Consequently, one concept works in a certain situation and fails in another. But motivating is so important in today's society and work environment that managers cannot afford to ignore any clues that may contribute to better worker incentives.

## WHAT MAKES SAMMY RUN?

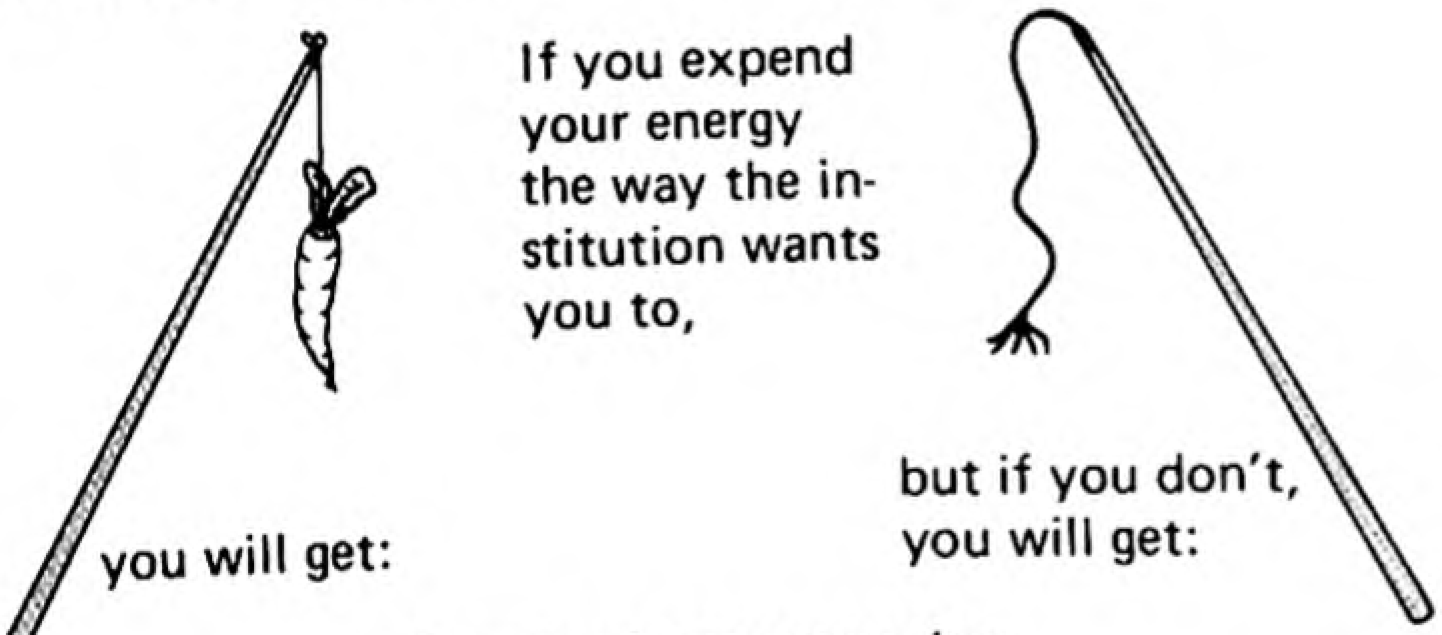
Motivation is a slippery subject. You cannot see, hear, or really measure motivation, but you can sometimes feel it. It is a vague impression of vitality (or sluggishness) among members of a group, or a charged atmosphere of involvement (or discontent). Even when we sense the feeling of motivation for or against something, we are only sensing the effects, not the cause. We can observe what has occurred with precious few clues of how it has come to be.

A motive is an inner drive, impulse, or intention that causes a person to do something or act in a certain way. In days of legal slavery, the motive of the enslaved workers was to survive, to get enough to eat, and to escape pain. As practices changed, employers substituted wages for whips. Yet the impression remained that wages could be used like whips; cutting pay would instill the same fears of starvation and pain that came from lashings or confinement, and raising wages would act as a release from confinement or the whipping post. The power of wages was undisputed until this century. Now it is generally recognized that wages, while still important, do not possess the dominant influence previously accredited to them. Man does not live by bread alone.

Human institutions are formed essentially to motivate people. A business enterprise focuses human energies toward profitable production. Governments channel the energies of the citizenry toward social survival. Educational systems are designed to motivate people to accept cultural heritages. The list of human institutions goes on and on until it terminates with a huddle of two people, each trying to motivate the other to his views.

The businessman who goes fishing when he should work, the politician who goes golfing instead of going to a legislative session, the student who goofs off or drops out rather than attending school, and the listener who does not respond to the talker are all considered to be poorly motivated. They are not doing what the institution expected them to do. They are doing what seems personally important at the time. They are highly motivated for that.

The much discussed Hawthorne studies (see Chapter 1) initiated in 1927 aroused suspicion that much more was involved in work performance than wages and working conditions. Among other things, these studies revealed that workers were quite capable of restricting output at the expense of their personal finances and security. This "slowdown" might even be to gain acceptance from their fellow workers. Researchers found out what workers were doing and how they were doing it, but they did not know why. The "why" accounts for the continued interest in motivation.


If you expend your energy the way the institution wants you to,
you will get:
but if you don't, you will get:

. . . from business enterprises

| | |
|---|---|
| A JOB | FIRED |
| PROMOTED | PASSED OVER |
| SALARY INCREASES | NO RAISES |
| SECURITY | INSECURITY |

. . . from political establishments

| | |
|---|---|
| PARTICIPATION | INELEGIBILITY |
| APPOINTED | EXCLUDED |
| ELECTED | DEFEATED |
| FAME | OBSCURITY |

. . . from educational systems

| | |
|---|---|
| ADVANCED | FLUNKED |
| PRAISE | CONTEMPT |
| GRADUATED | EXPELLED |
| HIGHER DEGREES | NO DEGREES |

*Fig. 9-1. Society's reward and punishment system.*

In today's affluent society, wages have ever less influence on human behavior. Loss of a job is not as disastrous as it used to be. Workmen's compensation, unemployment benefits, medical-aid insurance, savings plans, and a host of other socialized programs insulate workers from wage punishment as a motivator. And wage bonuses often fail to spark the desired behavior because rewards, too, have been blunted by affluence. What indeed makes Sammy run?

If the old reward and punishment system as depicted in Figure 9-1 does not work well in modern society, something must be replacing it. Psychologists, behavioral scientists, and other professionals are searching for just what it is. Many explanations and theories have been suggested as we will see in later pages of this chapter. The accumulated wisdom of these suggestions is a challenge to managers (1) to make the job itself so interesting that it becomes its own reward, and (2) to create an environment in which employees find opportunities for personal growth and satisfaction.

## NEEDS, DEEDS, GOALS, AND GAINS

From the viewpoint of psychology, motivation is anchored by (1) *needs* that operate within an individual and (2) *goals* in the environment which the individual

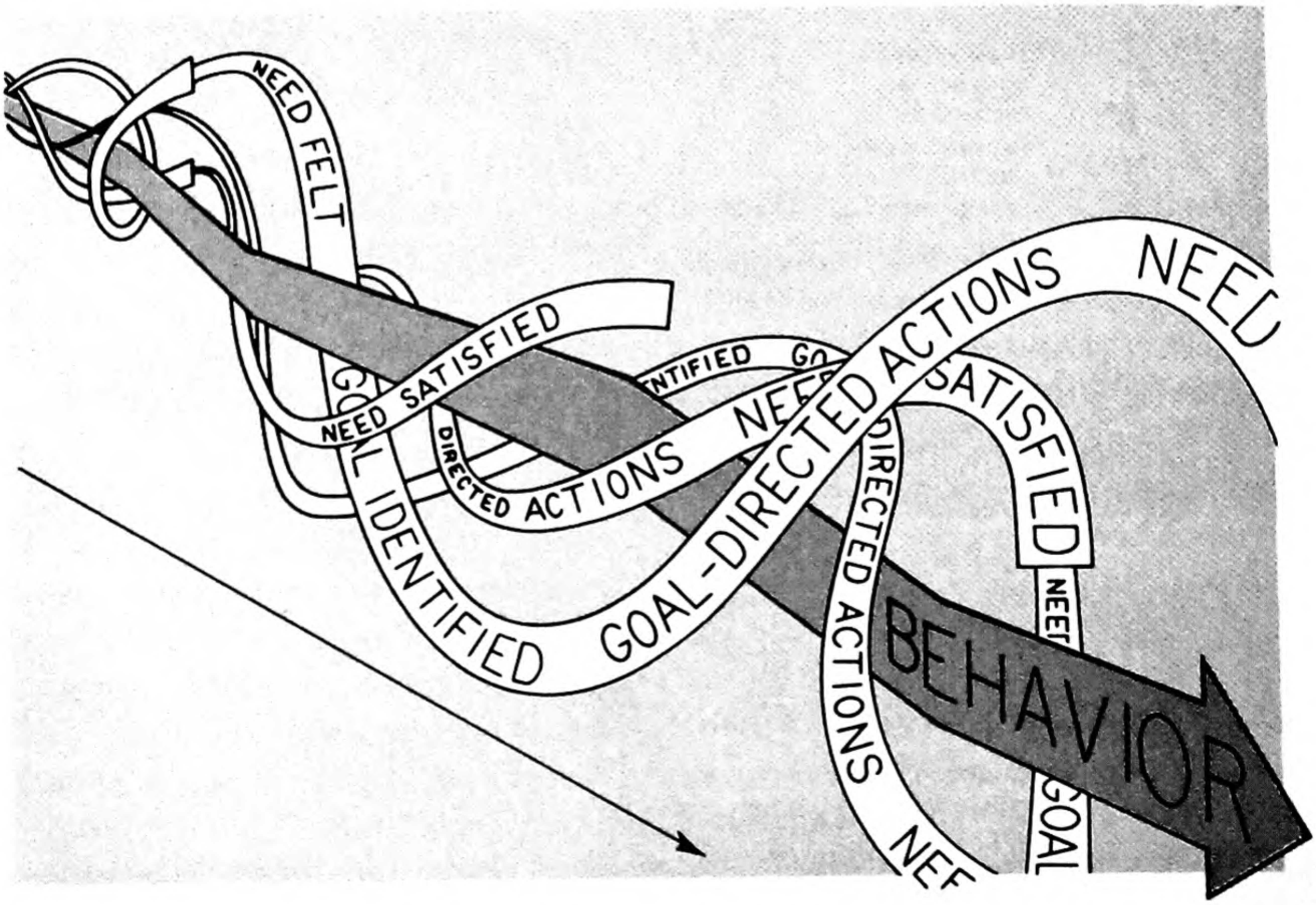


*Fig. 9-2. Human behavior is motivated by the needs an individual feels and the goals he seeks to satisfy his needs. Many needs of varying strengths vie for attention and influence actions. Needs, goals, and reactions to motives change with time.*

moves toward or away from. In one way or another (and many of them are very subtle) all human behavior can be linked theoretically to the needs people feel, and the way they go about satisfying those needs. As pictured in Figure 9-2, the motivation cycle starts when a need is felt. This felt need leads to the identification of a goal that will supposedly satisfy the need. Behavior is directed toward achieving this goal. Successfully attaining the goal may satisfy the original need which allows another need to take its place as the impetus for the next motivation cycle.

Since needs and goals are considered by many to be the fundamental source of behavior, we shall examine some of the theories proposed to explain their influence. Generally speaking, psychologists assume we learn what goals are relevant by a process of trial and error. This learning starts very early in life when a baby thrashes around, seeking means of contentment. Results of the thrashing can be successful, unsuccessful, or may even increase discontent. In the jargon of experimental psychology, these instances respectively represent reinforcement, nonreinforcement, or negative reinforcement of need-to-goal relationships. The trial and error process is a life-long ritual. Just as an infant learns that actions which bring success are valuable, adults accumulate experiences gained in attaining past goals that should be valuable in the future. The message to managers here is to try to help workers attain their goals through appropriate deeds. In other words, when an employee is seeking a goal, assist him by recognizing through reinforcement, nonreinforcement, or negative reinforcement the approved means of goal achievement.

A need creates a tension in a person. The amount of tension is a function of how strong the need is. When a person has been deprived of something for a significant period, the tension is greater. The longer someone has been deprived of water, the more the tension for a drink increases. Goal-directed behavior is the thirsty person's actions to obtain a drink. Once a good long drink has been downed, the need has been satisfied and the goal diminishes in importance. Drinking more liquids is not as satisfying because the driving tension has been relieved.

A need with a high expectation of achievement is generally more motivating than one with only a remote chance of being satisfied. This concept reveals an interesting connection between human behavior and history. In primitive societies personal needs focused on simple goals of subsistence. As the basic needs for survival were satisfied, goals became more personal. We still need food and shelter, but now we tend to specify what foods we want, the style of clothing, and the type of house. Relief from the strife of gaining physical security has extended the scope of needs to include goals unthought of in the past. The accumulated effect of this freedom is apparent in the rapid advances in science and technology which characterize our present society. The new freedom has also altered the management methods in today's industrial scene.

## THEORY X AND THEORY Y

The distinction between management polices based on control over the physical needs of workers and policies inspired by more indirect forms of motivation has been captured nicely by Douglas McGregor's Theory X and Theory Y.[1] The old-fashioned, traditional management approach is titled Theory X. It depicts a harsh attitude toward employees based on the following beliefs:

1. Employees inherently dislike work and will resort to all kinds of self-serving and disruptive practices to avoid it.
2. Since employees cannot be trusted to do the work expected, most of them must be strictly watched, controlled, and threatened with punishment if the desired work is to be accomplished.
3. Strict controls and threats produce desired results because most employees actually appreciate rigid leadership that lets them avoid job responsibilities. They react to threats because they prize security above all other factors in their job.

Although the points in Theory X may sound to us like a satire on unenlightened management, the theory does call attention to prejudices that led to labor unrest in previous generations. And, there is just enough logic twisted into Theory X to make it appeal to some intolerant managers today. Figure 9-3 diagrams the evolution of management practices that has drawn employers closer to employees.

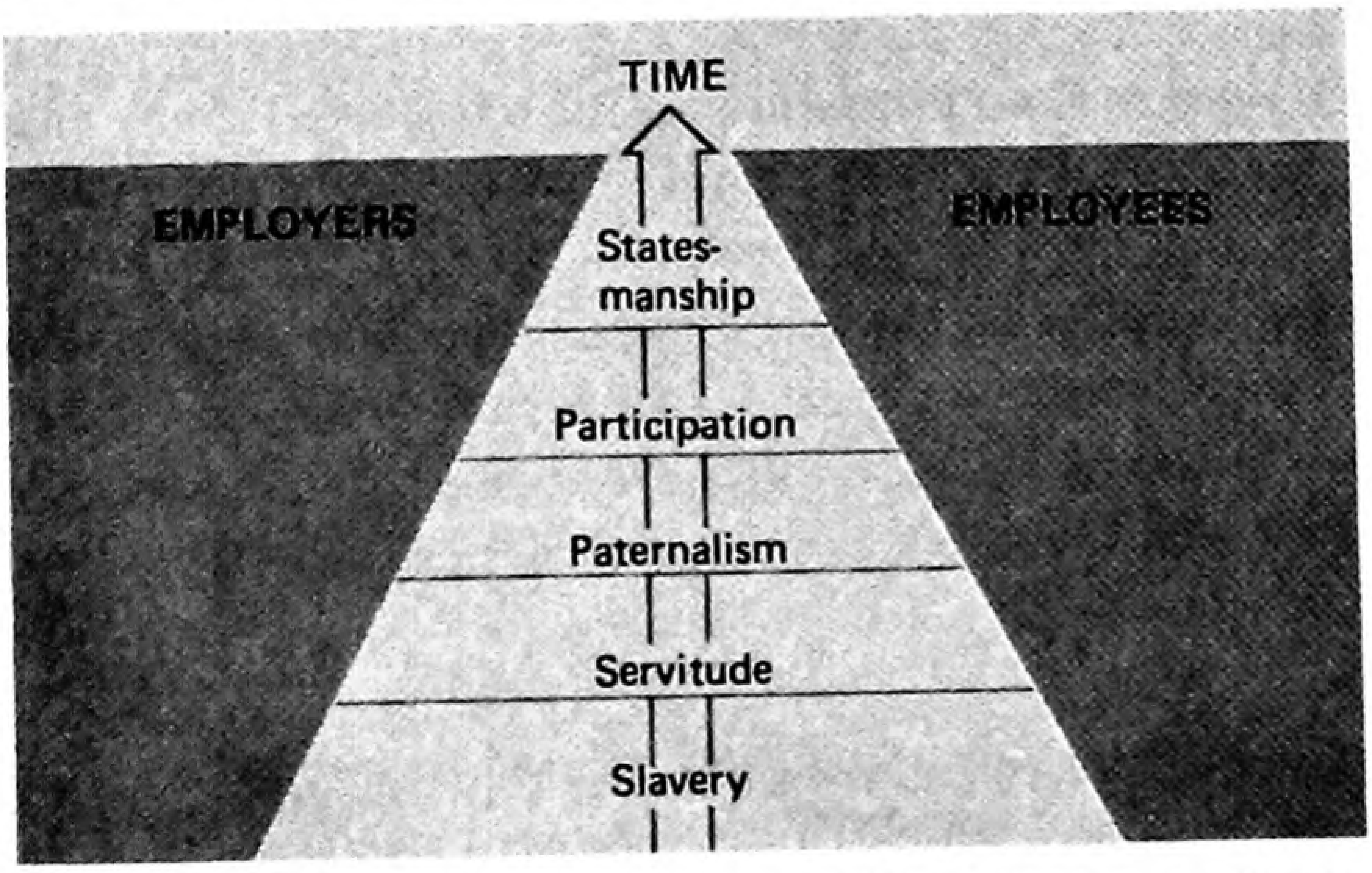


*Fig. 9-3. Modes of management are changing to bring employees and employers ever closer. The age when a "master" could dictate to his subjects without challenge has vanished. The "father image" of the organization head watching over the affairs of his flock of employees is fading. The modern leader is distinguished by his ability to bring about cooperation among reluctant factions, to see and understand both sides of a question, and to act diplomatically.*

Theory Y is the counterpart to Theory X. The difference between the two views is the emphasis on the human element in Theory Y. Employees are treated as feeling, principled individuals, not just as numbers to be manipulated. The assumptions underlying Theory Y are:

1. Employees do not inherently dislike work. They are anxious to use their abilities if given a fair opportunity.
2. Employees do not need to be supervised closely or threatened with punishment in order to get work done properly. They will direct themselves toward self-accepted goals, and the pursuit of these goals can produce the desired work.
3. Responsibility and self-direction are sought, not shunned, by most employees. They value security but also actively seek other goals that use and reward their creativity and intellectual potential.

Management's mission in the application of Theory Y is to establish work conditions that foster cooperation and enthusiasm. Cooperation is required to align employee goals with employer needs. Enthusiasm encourages employees to commit their diverse talents to objectives without promises of specific rewards. High employee morale does not ensure high output, but it increases the chance of realizing the advantages promised by Theory Y.

## NEED-RANKING THEORY

The backdrop for Theory X, Theory Y, and most contemporary views of motivation is the concept that man is motivated by many needs which can be grouped categorically in order of relative importance. Psychologist A. H. Maslow has developed a widely adopted framework for a *hierarchy of needs*—needs arranged in order of importance under the assumption that a lower-level need must be satisfied before the next higher need becomes a motivating factor.[2] This ladder of needs was shown in Figure 1-4 of Chapter 1 and is expanded upon below. The needs are listed in ascending order of importance.

**PHYSIOLOGICAL NEEDS.** The body needs food, water, shelter, and sex. Since these needs are largely provided for at this time in our culture, they are not significant motivators.

**SAFETY NEEDS.** The needs for protection from physical harm, sickness, economic disaster, and unexpected emergencies. An example of the transition from physiological to safety needs as motivators is the way demands of labor unions have changed. In earlier years, the unions demanded greater pay. Recent negotiations emphasize accident prevention, guaranteed annual wages, job security, and other fringe benefits.

**SOCIAL NEEDS.** The needs for companionship, affection, and a feeling of belonging. From the managerial standpoint, this level of needs marks the departure from essentially economic goals to a quest for mental health. Satisfied social needs are apparent in a work situation when an individual becomes so much a part of the group he is working with that he sees the group's efforts as his own. When he identifies closely with the group, he is more likely to contribute to its progress, which he terms "our" progress rather than "their" progress.

**EGO NEEDS.** The needs for self-esteem and the respect of others. In an occupational setting, ego needs involve a personal feeling that the content of the job is worthwhile and that others recognize this worthiness.

**SELF-FULFILLMENT NEEDS.** These needs Maslow defines as the "desire to become more and more what one is, to become everything one is capable of becoming." They are entirely an individual choice; the individual sets and attains his own goals to his own level of satisfaction. Full personal potential can be realized in any occupation. It matters not whether a person is a lawyer, secretary, corporate president, janitor, professor, or mother when seeking self-fulfillment. What counts is the drive to be effective in that endeavor.

While need theory assumes that lower needs are the most primitive and urgent, it also implies that attaining higher needs is indicative of growth and development by the individual. The passage from one level to the next is not automatic. On occasions an individual may be forced to forfeit safety to fight for food or to sacrifice social needs in order to ensure safety. Such backsliding or even being stuck at a level below expectation leads to frustration. Reactions to frustrations range from trying harder to giving up. In either case, until the obstacle is overcome and the need tension is relieved, a person remains emotionally stunted. Thus need theory suggests that a role of management is to assist employees in achieving (and recognizing they have achieved) their level of need maturity, and that the manager's reward is a more competent organization plus his own maturity.

## TWO-FACTOR NEED THEORY

Another explanation of how needs influence behavior has been advanced by Frederick Herzberg.[3] This theory is often referred to as the *two-factor theory of motivation* and is more job-oriented than Maslow's need hierarchy.

| | |
|---|---|
| **MOTIVATIONAL FACTORS** (factors that increase motivation when satisfied) | 1. Achievement<br>2. Advancement<br>3. Recognition<br>4. Responsibility<br>5. The work itself<br>6. The possibility of growth |
| **MAINTENANCE FACTORS** (factors that cause discontent when not satisfied) | 1. Company policies and administration<br>2. Interpersonal relations with supervisors<br>3. Interpersonal relations with subordinates<br>4. Interpersonal relations with equals<br>5. Job and financial security<br>6. Personal life<br>7. Quality and competence of supervision<br>8. Salary level<br>9. Status associated with work environment<br>10. Working conditions |

*Fig. 9-4. Positive and negative factors affecting motivation.*

Herzberg suggests that factors influencing behavior on a job can be classified into two categories: *Maintenance* factors and *motivational* factors. The elements involved in each of the factors are displayed in Figure 9-4. According to the theory, the factors have the following characteristics:

1. Maintenance factors are needs which do not increase motivation when they are satisfied, but do detract from motivation when they are not satisfied. They are associated with general conditions in the work environment, not the work itself. For example: For most people, a clean place to work and air conditioning are appealing enough to be maintenance factors.
2. Motivational factors are high-level needs which contribute to strong motivation when satisfied, but do not necessarily lower morale when not fulfilled. They are closely related to a job, its work content, and its position in the organization. Example: A chance for promotion within the organization will appeal to most people. Also, a challenging assignment such as having to survey an entire marketing area and write a report would be motivational to a marketing major.
3. An individual whose behavior is influenced by motivational factors is likely to be content with less than complete satisfaction of the maintenance factors, but the reverse is not true. Example: Let us take the case of the person, again, who is motivated by a chance for promotion. As long as he feels that he has an opportunity to be promoted, he will not be unduly concerned about whether or not the air conditioning is there or whether it works at 100 percent efficiency if it is there. On the other hand, the person who cares only about air conditioning and a clean place to work and has no ambition to be promoted within the organization may be very unhappy if these conditions are not met.

Thus, a highly motivated person will continue to be productive when some of his work relationships are not ideal, while a person striving to satisfy just his maintenance factors is easily bothered by any deficiencies in the work environment.

## FROM THEORY TO PRACTICE

Theories provide a framework by which we can view happenings around us and better understand the reasons behind the happenings. Need and goal theories direct attention to certain aspects of behavior that otherwise would be overlooked or be deemed unimportant. They help explain some actions that seem awkward or hard to understand. Not everyone agrees completely with the theories, however, particularly the two-factor motivating concepts. Lack of agreement is surely not serious. It is quite predictable for a subject so open to appraisal. But it does serve to remind us that we do not have all the answers. Need and goal theories may seem to be so simple and logical as to not require explanation. While this very simplicity appeals to many people, ways of converting the theories to practice are not directly apparent nor simple to undertake.

In addition to setting a reference framework, theories should also serve as a foundation for erecting operational plans. In the following sections we will consider several motivational methods that draw on needs and goals concepts. Just as the theories have been questioned, so the plans designed to implement the theory concepts have been criticized. Again, criticism should not condemn the plans; it should serve only as a precaution.

To get an idea of the difficulties involved in motivation, try to solve the age-old problem of how to inspire students to learn. The theories about motivation help but do not fully explain students' behavior. It is obvious that studying is difficult with an empty stomach, under uncomfortable conditions, or in sickness or fear. The importance of social contacts with other students is also apparent. These observations could be classified as satisfying the physiological, safety, and social needs or the maintenance factors. Yet we know that when these needs are met many students still balk at education. Perhaps Theory Y should govern the thinking of teachers as they relax rules and encourage pupils to see the advantages to be gained and the challenges of education. Maybe more emphasis should be given to recognition for high achievement, the fulfillment gained from knowledge that extends personal horizons, or the satisfaction and growth obtained from the act of studying. But how?

When you think back over your own schooling you can probably recall instances when most of these motivational techniques were tried on you and your fellow students. Some got through and some didn't. Which ones got through differed among individuals. The motivating impact varies with the situation at the time and the state of maturity of the individual. What works once may fail on the next application. The same irregularities plague all motivation methods. What works for one manager fails another. Each of the following plans has enthusiastic advocates and each has disillusioned detractors. The art of management includes knowing what is available and then adapting it knowledgeably to fit the given situation.

## JOB ENRICHMENT

Job enlargement, as described in Chapter 7, particularly vertical enlargement, embodies many of the concepts of job enrichment. Both methods seek to involve workers more intimately with their work. The difference is one of emphasis; job enrichment attempts to bring the job content up to challenge the skill level of the worker hired to do the job.

Herzberg, a strong proponent of job enrichment, stated the following in his article "One More Time: How To Motivate Employees," *Harvard Business Review*, January-February, 1968:

> Not all jobs can be enriched, nor do all jobs need to be enriched. If only a small percentage of the time and money that is now devoted to hygiene (motivational factors), however, were given to job enrichment efforts, the return in human satisfaction and economic gain would be one of the largest dividends that industry and society have ever reaped through their efforts at better personnel management.
>
> The argument for job enrichment can be summed up quite simply: If you have someone on a job, use him. If you can't use him on the job, get rid of him, either via automation or by selecting someone with lesser ability. If you can't use him and you can't get rid of him, you will have a motivational problem.

An example of job enrichment was described in "Motivating People: Money Isn't Everything," *Newsweek*, April 22, 1968.

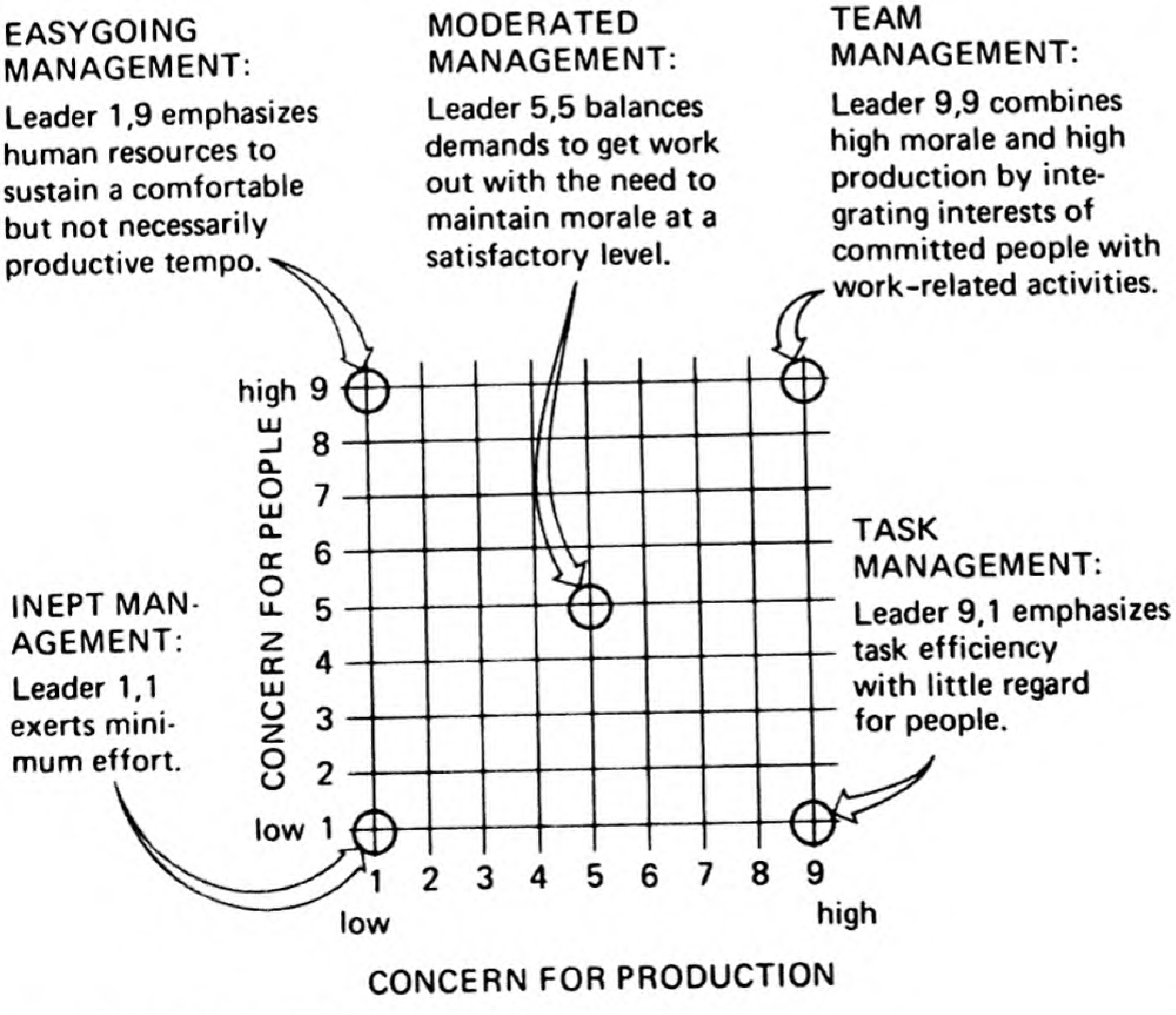
> Herzberg himself worked closely with the company in setting up the projects, including a 1965 test run in AT&T's troubled department of shareholder relations. There, women—70 percent of them college graduates—were plainly unhappy in their jobs, and with reason. They

> were second-guessed every step of the way in their handling of correspondence from AT&T's 3.1 million stockholders. Herzberg's solution: lift supervision, let the girls write and sign their own replies, encourage them to become experts in problems that interested them. "All we did, really, was let them run their own jobs," . . . . . The upshot: turnover dropped, productivity rose to above pre-test levels, and job satisfaction, measured on a scale of 100, soared from 33 to 90 in six-months—all without a pay increase.

## MANAGERIAL GRID

The style of leadership employed by a manager undoubtedly affects motivation and employee behavior. Just how physical and mental traits or different styles of personal behavior affect leadership has long perplexed both management scholars and practitioners. As with motivation, many theories have been proposed. We will consider just one approach of recent vintage that has been widely applied for training individuals and groups.

The *managerial grid* concept is based on research into the personal behavior of leaders and is best known for its application to management development programs.[4] Part of its success is due to the graphic format used to focus attention on different styles of leadership. The appropriately named *managerial grid* is



EASYGOING MANAGEMENT: Leader 1,9 emphasizes human resources to sustain a comfortable but not necessarily productive tempo.

MODERATED MANAGEMENT: Leader 5,5 balances demands to get work out with the need to maintain morale at a satisfactory level.

TEAM MANAGEMENT: Leader 9,9 combines high morale and high production by integrating interests of committed people with work-related activities.

INEPT MANAGEMENT: Leader 1,1 exerts minimum effort.

TASK MANAGEMENT: Leader 9,1 emphasizes task efficiency with little regard for people.

*Fig. 9-5. The managerial grid.*

depicted in Figure 9-5. Each intersection represents different leadership characteristics. Descriptions of leaders classified by the four extreme positions and the center of the grid are shown in the diagram.

Leadership can be defined as the process of influencing followers to accept direction and control. In the grid, leaders are classified as to what degree they are production-oriented and people-oriented. Research has suggested that higher production can be expected from groups led by an employee-centered manager —one who builds effective groups with high performance standards by fully communicating work objectives to subordinates and then allowing them considerable freedom in the way the work is to be accomplished.[5] It appears, then, that a leader who exhibits 9,9 characteristics is the ideal person for any supervisory position. Assuming that an ideal leader should indeed devote high concern simultaneously to both people and production while concurrently satisfying both superiors and subordinates, it is obvious that such leaders are rare. Proponents of the managerial grid suggest that programs based on the grid can assist leaders to move toward a 9,9 classification.

Participants in a managerial-grid program study ways to improve individual effectiveness for one-to-one relationships, team skills for getting maximum results from joint efforts, intergroup relations for solving problems between organized groups, and corporate culture for analyzing work and introducing changes. Much of the success of these programs comes from using company personnel, not outsiders, to run the programs. The training must involve all levels of management. The conceptual framework provided by the grid tends to encourage a common reference theme for discussions.

## SENSITIVITY TRAINING

Leadership, motivation, and personal awareness are also treated through the somewhat controversial technique of *sensitivity training*. This training is usually conducted at some location other than the normal place of work. For a most effective group, the organizer gathers a small number of people with generally common interests. They need not be from the same job level of their organization. Each member of the T group (training group) examines how he affects and is affected by other persons in the group. This assessment is made in a free exchange of opinions and frank views which has no agenda and no formal focus. Sessions are designed to make participants more sensitive to themselves and to others. The basic assumption here is that lack of sensitivity causes poor task performance in work that requires group effort. Correspondingly, high sensitivity can supposedly reinforce motivation individually and for teams.

The ultimate test of any form of training is whether or not it increases the desired skills of the trainees. The results of sensitivity training are mixed. It is generally credited with helping participants examine their own underlying conflicts and increasing their awareness of the interdependence of individuals within groups. Sometimes these values cannot be carried over to the work place. The participant returns to the same work surroundings and coworkers he had before the training, an environment where the behavioral insights found in his T group may not be accepted or wanted by those without the special exposure. The stress of the training encounters may even produce negative changes in the participant's ability to perform his tasks.

Thus the potential of sensitivity training to loosen some of the blocks to effective communication and team effort should be evaluated in terms of how, and whether or not, an organization can benefit from the realized potential.

## MANAGEMENT BY OBJECTIVES

Management by objectives (MBO) is a managerial motivation technique that has received worldwide attention. It has acquired a legion of advocates from all types of industries and government agencies since Peter F. Drucker first introduced the concept in *The Practice of Management* (Harper & Brothers, New York, 1956), saying, ". . . management by objectives and self-control may legitimately be called a 'philosophy' of management. It rests on an analysis of the specific needs of the management group and the obstacles it faces. It rests on a concept of human action, human behavior, and human motivation" (p. 136).

According to Drucker, MBO is especially valuable to managers because it allows them to control their own performance. This feature contributes to stronger motivation by satisfying higher motivational factors.

George Odiorne, another speaker for MBO, suggests that the MBO process aids motivation of all participants through having superior and subordinate managers jointly identify common goals, carefully define them, and together monitor progress toward achieving results.[6] Need satisfaction is theoretically simplified when a goal is distinctly evident and progress is obvious to all. Intuitively we can sense that a person is more enthusiastic when he can plainly see his goal and how fast he is progressing toward it. By coordinating personal goals with the aims of the administrative unit, participants gain added incentive to improve work performance.

The implementation of an MBO program includes the following operational steps:

1. A meeting between a superior and subordinate is arranged to discuss goals for the subordinate that conform to the organization's goals as explained by the superior.
2. The subordinate takes the lead in establishing priorities for his duties that will support the organization's priorities. The superior and subordinate jointly agree to what is expected during the operating period, what criteria will be used to measure accomplishments objectively, the need to acquire any special resources, and dates for review of accomplishments.
3. Subsequent meetings between the subordinate and superior are held to discuss progress on the goals and any modifications that might be necessary due to changes in other parts of the organization.
4. All agreements on objectives and performance appraisals are mutually committed to writing for use in reviews and merit evaluation procedures.

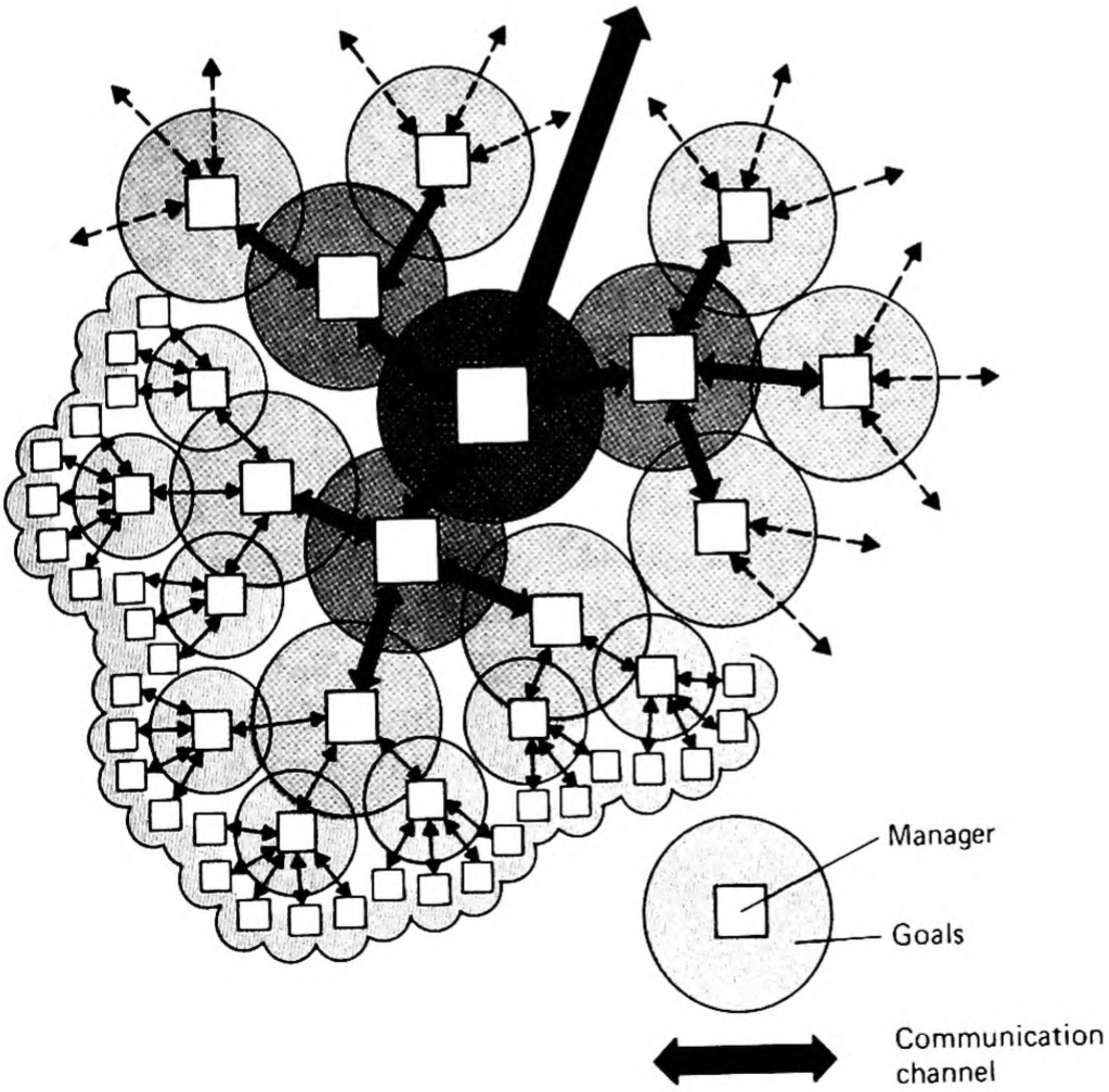


*Fig. 9-6. Relationship of goals to channels for communicating guidelines and results.*

Figure 9-6 shows both the way objectives are integrated and the flow of information in the MBO process. A superior draws his objectives from the organization's policies. The tactics required to implement his objectives involve actions by his subordinates. Their accomplishments then are his accomplishments and, correspondingly, his goals are their goals. These linkages between goals and accomplishments carry through all managerial levels of the organization, becoming more detailed and output-oriented as they approach the firm's actual production levels.

Management by objectives, in common with other techniques designed to improve leadership and motivation, has plus and minus aspects. Looking at the negative side first, MBO programs prove unproductive if the higher levels of management are not sufficiently convinced of its value to devote the time needed to make the superior-subordinate exchanges useful. And the exchanges, including preparation and reviews, do consume substantial blocks of time. The associated paperwork also adds to the administrative burden.

Points on the positive side for MBO programs include

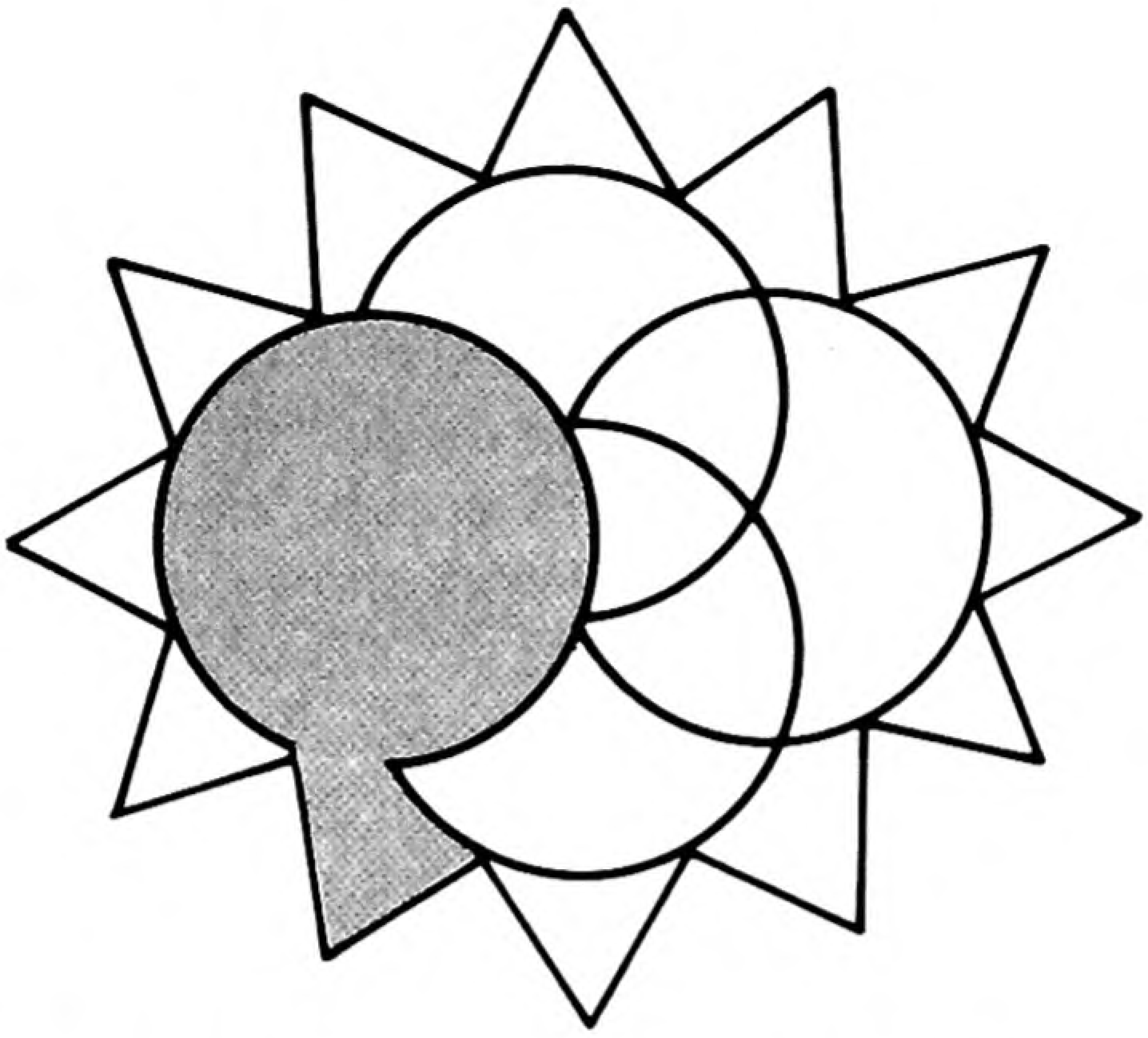
1. Improved personnel development through setting goals at the limit of current capabilities to encourage growth
2. Improved communications resulting from scheduled appraisal sessions where key aspects of the work are ensured consideration by the previously agreed-upon agenda for performance reviews
3. Improved perspectives for both superiors and subordinates as a result of counseling that purposely looks at both sides of each situation
4. Reduced anxiety by subordinates about their jobs because they are kept up to date about how superiors feel toward their work performance
5. Greater objectivity in rating work performance because the identification of goals includes establishing quantitative means to measure progress
6. Higher morale resulting from the opportunity to help decide what is included in a job and from recognizing how the job content contributes to meaningful objectives

Drucker got right to the core of the implementation issue when he stated, "And yet the ultimate test of management is business performance." Motivation is a difficult concept to grasp, as we noted at the beginning of this chapter, yet it continues to preoccupy managers because its effects always influence business performance.

## REFERENCES

1. Douglas McGregor, *The Human Side of Enterprise*, McGraw-Hill Book Company, New York, 1960.
2. Abraham H. Maslow, *Motivation and Personality*, Harper & Brothers, New York, 1954.
3. F. Herzberg, B. Bausner, and B. Snyderman, *The Motivation to Work*, John Wiley & Sons, Inc., New York, 1959.
4. Robert R. Blake and Jane S. Mouton, *The Managerial Grid*, Gulf Publishing, Houston, 1964.
5. Rensis Likert, *New Patterns of Management*, McGraw-Hill Book Company, New York, 1961.
6. George Odiorne, *Management by Objectives*, Pitman Publishing Corporation, New York, 1965.

# Chapter 10



# Coordinating

**KEY SUBJECTS**

*Coordination of activities depends on the skill of the leader, the type of group he leads, and the situation in which the group operates.* A leader is known by his sense of purpose, degree of influence, and drive. But there is neither a single pattern of traits that identifies a good leader nor a dominant rule that solves leadership problems. However, there are guidelines and organizational arrangements that promote better cooperation.

Employees are divided into organized work groups. The formal grouping may, but probably does not, coincide with membership in interest groups. Both groupings influence work performance.

Emergency situations are particularly challenging to managers. Beyond the responsibility to correct immediate trouble is the potential to institute changes during the recovery period. "Management of change" is a vital part of coordination because all organizations are subject to strong forces, internal and external, that demand changes. Sometimes the initiation of a change causes an emergency. Successful adaptations rely on management's dedication and tolerance.

*Information flow links management decision making to output-directed operations.* An information sender seeks to inform or sell and the receiver collects and evaluates. Barriers to person-to-person communications can come from failure to listen, relate, or level. Ever-improving automated data processing systems have made impressive contributions to information recording and accessibility.

*Inventory management enhances coordination by insulating each work operation from disruptions in other operations and by stabilizing overall employment.* The advantages gained from a policy to store materials must be evaluated against the carrying costs for the inventory. These costs include charges for space, insurance, taxes, obsolescence, deterioration, and capital invested.

*The economic order quantity is determined by balancing ordering cost against carrying cost.* It can be found by tabular, graphic, or algebraic methods. Calculations are simplified by assuming the inventory is used at a constant rate and that replenishments arrive instantaneously.

*Refinements to the basic inventory model allow consideration of materials being used as they are received, placing extra-large orders to take advantage of quantity discounts, and fluctuations in the usage rate and lead time.* To guard against losses from running out of stock, the careful manager maintains a reserve supply. Determining how large this safety stock should be is complicated by the difficulty of estimating the cost of a stockout and the fluctuations in supply and demand.

## COOPERATION

> My title is *coordinator*. People call me lots of other things too. I'm everybody's whipping boy. Whenever anything goes wrong, I get blamed, but when things are going OK, people keep asking me what I do with all my spare time.
>
> I really don't have any spare time. When things are running smoothly I am trying to guess what may go wrong in the next few minutes. After the trouble hits, and it always arrives sometime, I'm hopping all over the place to get it cleaned up. Usually I know who to call for help, where to go to get what's needed, or at least how to soothe the tempers that have flared. While repairs get underway, I start rerouting, finding substitutes, or spotting alternatives to keep people busy and to keep the pipeline flowing as full as possible. After things return to near normal, I sift through the wreckage to try to decipher what went wrong. And I write a report on it. Then I often have to make a report about the report to visiting big wheels. Got to show them what a coordinator does.

The foregoing testimonial could have been given by a person with the title of expeditor, program director, product manager, project coordinator, or any position created to direct attention toward a certain limited mission or goal. Such positions are held by specialists. They possess broad experience in the area of their specialty and have a reputation for being able to get along with, and get the best out of, the people with whom they work. They are known as "big picture" people but their repute rests on watching the little details that could ruin the total picture if left unattended.

All managers are concerned with coordination—the harmonious functioning of activities. An undertaking of any significance involves cooperation between participants to bring together skills or materials in a certain order to accomplish a mission. We earlier devoted a whole chapter to the concepts and methods of organizing. We discussed planning, scheduling, and allocating in later chapters. Coordination includes all these subjects and others wrapped together in a search for worker cooperation and work integration.

In this chapter we will consider three ingredients of cooperation: people, information, and materials. It is easy just to tell people to work together. Quite often they cooperate because they know they should. And quite often they appear to be cooperating but will not or cannot actually function harmoniously. Then the manager has to earn his title by applying his diplomatic skills, securing accurate information, and ensuring that work is not thwarted by lack of materials.

## TEAMSMANSHIP

Occasions are rare in which a manager can accomplish a notable feat strictly through his own efforts. Solo undertakings are, by definition, not really managerial applications. Organizing and coordinating his own affairs are, of course, vital to a manager as prerequisites to his primary function of organizing and coordinating other people's activities. His accomplishments are a reflection of his team's accomplishments.

A manager's ability to coordinate group activities depends on the combination of his personal attributes and the group's characteristics, as well as the situations encountered. In this section we will consider the factors displayed in Figure 10-1. A leader is known by his sense of purpose, degree of influence, and drive. The make-up, attitude, and orientation of individuals within a group affect its operation. The situation in which the group operates varies from comfortably familiar to alarmingly strange. All these factors contribute to the success of a mission that has only a given amount of support.

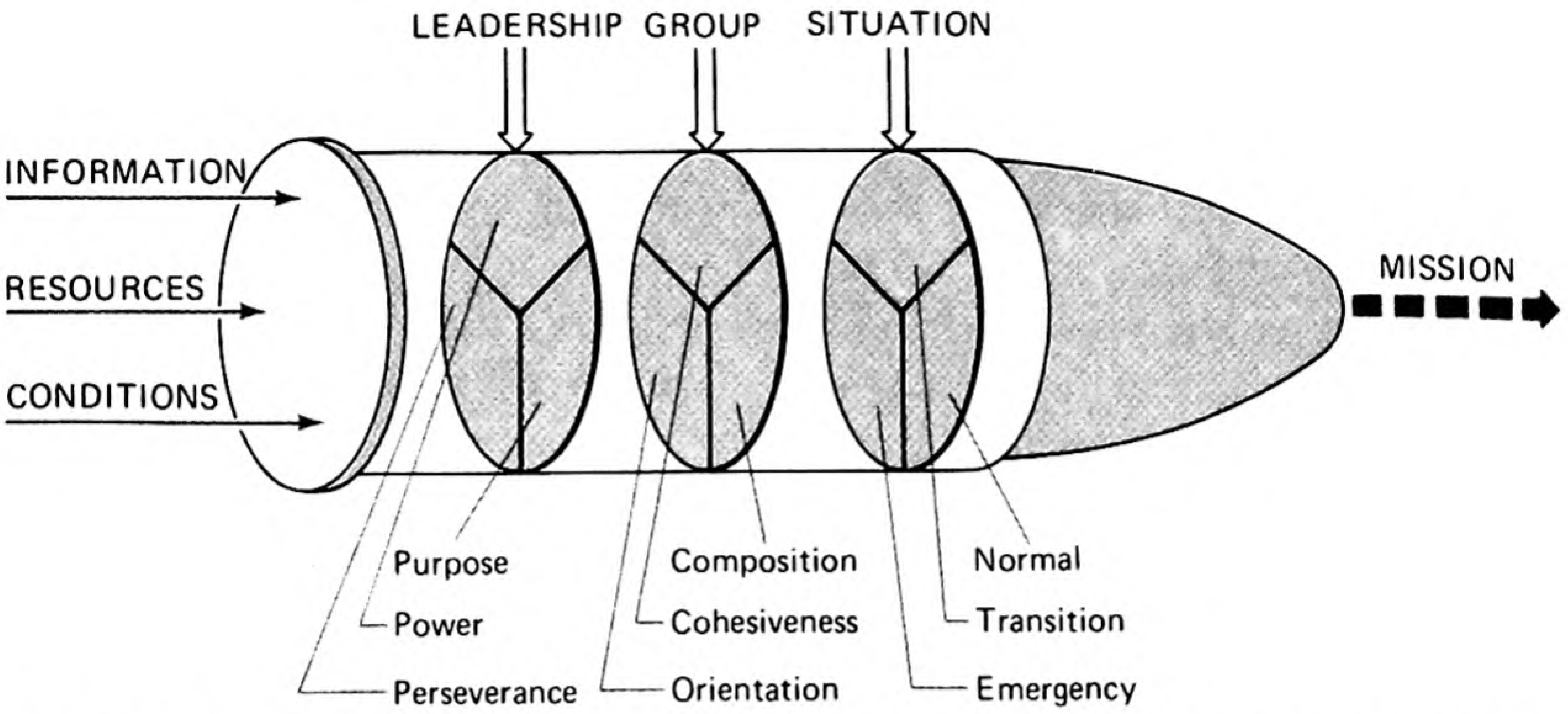


*Fig. 10-1. A task to be accomplished under certain conditions and with a specific level of support is assigned to a leader and his team. How well the mission is accomplished depends upon the skill of the leader as he directs a group of unique characteristics in a specific situation. The total effect is akin to firing a bullet at a target. The propellent is the support provided. The aim is the task assignment. Ballistics depend on the leader, team, and situation.*

### The Leader

Abundant studies devoted to the qualities of leadership have helped explain what is involved in leadership but have not led to a guaranteed process for producing leaders. So many talents and styles of leadership are used to confront so many different conditions that even cataloging the traits possessed by a single acknowledged leader yields a long list. Physical bearing, personality, and intelligence are surely important factors, but examples can be found to refute almost any generalization about whether better leaders are large or small, stern or relaxed, brilliant or average.

In the same way different threads of traits can be woven into the fabric of leadership, so different rules can apparently guide the weaving without blemishing the product. The following points are a sample of reasonable suggestions for developing leadership qualities:

- Base actions on personal integrity and provincially accepted ethics, not the shortcuts that work only once.
- After a decision is made, support it; and when you make a mistake, admit it. *Co* means *with* and *operation* means *doing,* so cooperation means *doing with,* not *doing for.*
- Look for results rather than recognition, and acknowledge both.
- Search for the real problems instead of the "apparent" ones: many complaints are just symptoms of the real trouble.

- Be realistic in setting goals and explain assignments thoroughly; unclear or unreachable goals can reduce a challenge to a mockery.
- Follow up on performance but do not continually "look over their shoulders."
- When criticism is warranted, criticize the fact rather than the person.

It is safe to say that many, many items could be added to the list, and it still would be an incomplete guide. Even in the most ordinary forms of supervision, a bewildering variety of situations arise to challenge the leader's talents. First-level supervision produces many frustrating encounters, especially for first-time leaders. However, if these encounters are remembered, they become rewarding and sobering reminders that mold a leader's sense of purpose.

It is well accepted that necessary responsibility and authority should be allotted to each leadership position (see Chapter 3). These two allotments plus decision-making options associated with an office combine to establish a position's influence or power. Different leaders use power in different ways. Some rely heavily on power to punish and reward followers; leadership is then a series of threats and promises strung together to provoke spurts of action, often with bitter aftereffects. Sometimes the position itself is the source of leadership because everyone recognizes that whoever holds that position is automatically endowed with the power to make it worthwhile to follow whatever directives are issued. At other times the position held is only incidental to the personal traits and reputation of the position holder. Then leadership is derived from respect for the leader's talents or admiration for his personal characteristics.

Having leadership power, like having a brain, is useful only if it is exercised. A leader is supposed to influence the behavior of the group he leads. Often he can achieve the necessary cooperation by just being an example. But he should know what options are available when his leadership is challenged. And he should be willing to use them or be willing to give up his position of leadership.

*Perseverance* is the trait that keeps a leader leading. "Peter's Principle" suggests that people get promoted until they eventually reach a level of leadership that they can no longer handle. Dr. Laurence J. Peter calls this position the "level of incompetence" and half seriously concludes that most mature managers are occupying such positions.[1] From the viewpoint of leadership, we might observe that such "incompetents" have acquired the power of position but are no longer willing or able to apply it. They may not recognize what potential is available, or they may be wearied by its use. In either case, both the leader and the followers lose from the lack of direction.

### The Group

Whenever people gather for a sustained period of time, they form groups. In a work environment there are gangs, crews, shifts, offices, departments, and other formally organized groups. There are also informal groups made up of people with common interests. The two types of groups may match members, but probably do not. However, all the groups influence work behavior to varying extents.

A sample of possible groupings within a formal chain of command is displayed in Figure 10-2. Group 1 might be a recreation group that meets at lunch to play cards. Members of Group 2 could be a task committee of volunteers attempting to improve the employee benefit program. Group 3 might be a convenience group of employees living near each other who share rides to work. Note that membership in a group may be drawn from different work departments or even from other companies; this diversification partially accounts for the extensive grapevine communication network described in Chapter 3.

Each group operating in the organization has a nominal leader or spokesman. For the organization's management, this leader can be a source of opinions

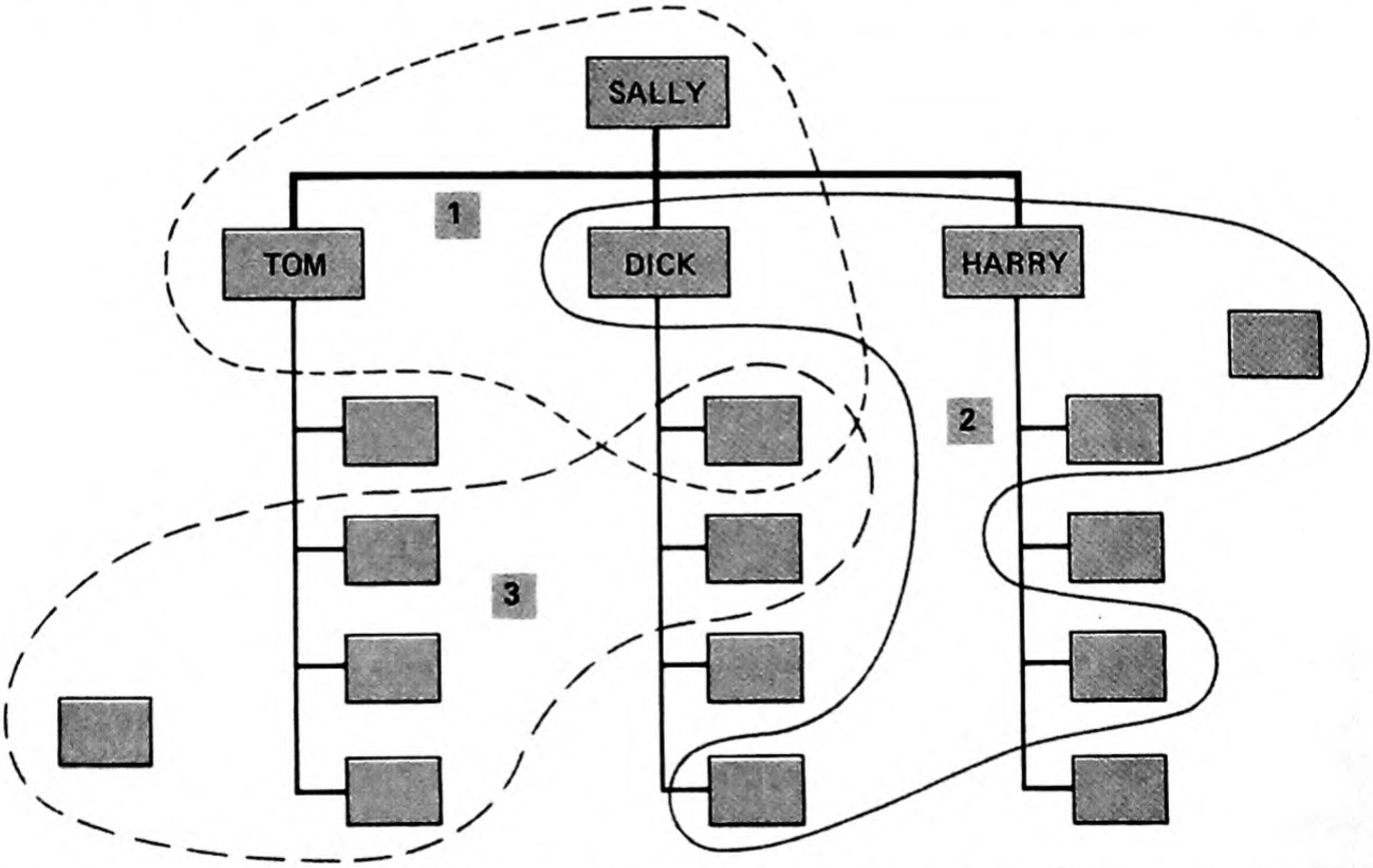


*Fig. 10-2. Formal groupings (bold lines) in an organization chart seldom correspond to interest groupings (numbered enclosures). Although the formal chain of command may function well in task performance, outbursts of trouble may be fomented by developments within the informal groups: rumors or grudges passed along, opinions given about fellow workers or common problems, hurt feelings carried to the workplace, etc. Conversely, personal satisfaction derived from group associations may compensate for poor working conditions.*

representing his group. He can also be the head of a pressure movement to further the group's interests.

Individuals in a group are influenced by group norms. This influence is perhaps most apparent in teen-age groups where cliques conform to their self-imposed dress codes and modes of behavior. Group norms in a work environment take the form of a common front raised by a group to oppose an action by managers, say, to change working hours; to resist higher quality standards deemed unfair by the group; to assist weaker members of the group to meet acceptable output levels; or to support a favored supervisor who has incurred the displeasure of his superiors.

While most managers recognize the importance of informal groupings within a work force, they are also aware of the difficulties of communicating with the groups. First, there is the problem of defining the group and its common interests. Then, the real leader must be identified for adequate contacts. Even when these problems are overcome, the solutions may be only temporary because the interests, composition, and cohesiveness of groups can change radically. Changes are sometimes hastened by the attention of managers. A group may feel that its leader is being "used" by management and is therefore no longer a legitimate spokesman. Or, a group singled out for special treatment may either attract new members or lose members because of the treatment.

Several observations developed from experimental studies of group behavior provide suggestions to guide management contacts with informal work groups.

- Groups are formed to satisfy the members' needs. A need could be economic, as when assembly line workers band together to cooperate on incentive wage plans; but more commonly groups satisfy social and ego needs.
- Work groups form slowly, only after members accept and learn to trust each other. When new employees are not immediately admitted into the group of their choice, they often become frustrated and angry.
- Work groups may be quite effective in enforcing their code upon members and even outsiders who work with, but are not members of, the group. Enforcement measures range from casual but firm suggestions to personal threats and job sabotage.
- A group member who holds a higher position in the formal organization does not necessarily hold a high position in the informal structure.
- Smaller groups are more cohesive than larger groups. There is some evidence that more cohesive groups provide more satisfaction and support for members.

- Groups in the same formal organization have status ranks based on the group's reputation for skill, salaries, promotion, and influence.
- Better work performance may result when workers are allowed to choose their partners for jobs requiring cooperation such as bricklaying, plumbing, fabricating, etc.

### The Situation

According to the "exception principle," reviewed in Chapter 8, very little attention should be devoted to a normal situation—an acceptable condition which is apparently conforming to expectation. Two dangers involved in ignoring a normal situation are: (1) The standards of performance may not be as good as they could be, and (2) troubles may accumulate undetected until they burst forth in exaggerated proportions. The first danger is minimized by establishing and adhering to well-conceived work standards, as described in Chapter 7. The chance of an undetected trend toward inferior output can be reduced by applying the control measures described in the next two chapters. Thus, it is valid for a manager to concentrate on the future when the present is placid, providing he is wary enough to catch the warning signs of potential disruptions.

A sudden emergency, the opposite of a normal situation, need not be too troublesome if the manager has done his homework. Planning for the unexpected is just good management. Admittedly, not all forms of emergencies can be anticipated, but the type that most seriously threatens the goals of the organization deserves some forethought. Nearly all organizations have disaster plans to confront emergencies such as a cave-in, riot, fire, explosion, strike, or breakdown. The disaster plans include individual action responsibilities and group activities to conduct after the emergency hits, stockpiling of resources for use during recovery, and alternate operating procedures to follow while conditions get back to normal.

Each year weather-caused calamities demonstrate the value of disaster planning and reveal the heroic efforts people make to cope with unanticipated events. During the summer of 1972 hurricane Agnes brought considerable devastation to river valley areas in and about Elmira, New York and Wilkes-Barre, Pennsylvania. The response of citizen groups and individuals to the critical needs of families and businesses in the areas was amazing. For no extra compensation amateur radio operators at Elmira maintained the only round-the-clock communications network when utilities were completely crippled. Untold lives were saved by their messages and information. Volunteers from as far as 50 miles away came by bus for months after Agnes—bringing needed supplies, clothing, and food to flooded-out families.

An interesting feature of most emergencies is the way people behave during the troubled period. Former grievances tend to pale in contrast to the dramatic events of a calamity. Cooperation is a natural response. Raw leadership from surprising sources may be summoned into action. Unrehearsed actions and bared emotions may reveal opportunities to make improvements during the recovery that were unrecognized or impossible before.

If equipment has been damaged or destroyed, replacements will probably include recent technological improvements. New equipment and renovated facilities usually are accompanied by changes in work procedures. These changes, as well as other modifications to the work routines, can be more easily introduced after the sharp break with the past caused by the emergency. Perhaps new talents discovered during the disruptions can be used and the cooperative attitude in effect during recovery can be sustained. The challenge to managerial leadership is often greater after than during an emergency.

Planned changes are far more difficult to initiate during normal conditions than after an emergency. In fact, the implementation of drastic changes has occasionally created emergency conditions: wildcat strikes, walk-outs, sabotage, and other maneuvers enacted to protest changes. Even minor changes can be viewed as emergencies by the affected employees. Since an individual's concerns may not be shared by other members of his group, mass reaction is not likely, but a disgruntled employee can soon spread discontent if he continues to feel abused.

That there is always room for improvement is implied by an offshoot of Murphy's Law: "Any time things appear to be going well, you have overlooked something." Conditions that invite change can be traced to external and internal causes.

Competitors' actions and changes in consumers' tastes require a dynamic response from a firm. Crash programs are frequently launched to salvage a product from a deteriorating market or to introduce a new model to compete with innovations made by other firms. Such tactics involve personnel throughout an organization as work groups are shuffled, schedules are revised, and priorities are renumbered.

Social legislation and pressure are growing external forces for change. Environmental issues have had a major impact on industrial expenditures which have, in turn, affected personnel. More direct personnel effects are attributable to anti-discrimination and safety-occupational health laws.

Internal causes of change result from inadequate performance by processes or people. Automated data processing and semi-automated production processes have been the source of major changes in the past decade. Specific "people-problems," such as a breakdown in employee morale as evidenced by high rates of absenteeism, turnover, or grievances, require changes tailored to restore motivation.

It is usually easier to recognize that a change is needed than it is to decide *what* change is best and *how* to make it. For example, a decision to introduce more automatic equipment into a production process could be spurred by difficulties in hiring qualified craftsmen for the present method of manufacturing. From an economic standpoint the proposal might appear faultless. However, after the automated line was installed, people-oriented problems might undo all the dollar-oriented advantages. The new line could prove monotonous and unattractive to workers, alienating the old employees and making it difficult to hire new ones. When morale sinks, minor personnel problems tend to be inflated. A whole set of unanticipated difficulties could convert the expected change for the better into a change for the worse.

There is no one best way to lead change, just as there is no one best guide to conduct all leadership situations. In a tightly structured organization such as a military unit, a detailed directive can accomplish a complete change. Sometimes a quick and painful switch is less disruptive than gradual modifications. More often, an explanation of why change is needed, followed by a chance for those affected to participate in the planning, will ease the transition. The participation is intended to reduce resistance to change and to find ways to minimize hardships resulting from new procedures. Retraining, early retirement, reassignment, and other ways to provide security for affected employees should be considered.

Although most people know that change is inevitable, they give in to the temptation to pretend it will affect someone else, not themselves. Leaders, too, are not immune from resenting change. They may actively push for changes in one direction while resisting a change in another. Both activities are perfectly logical tactics of leadership. The most important point is to recognize that both tactics are being used, and that other people also advocate or resist certain changes with logic. The management of change relies on both dedication and tolerance.

## THE NEED TO KNOW

Information is the oil that keeps an organizational machine running smoothly. The need to know is such an obvious part of management that it is easy to gloss over, to acknowledge merely that it is necessary and to assume it will be satisfied. But by whom? And how? It is somewhat ironic that each higher echelon of management is empowered to make more sweeping decisions, yet each higher level is further away from the actual experiences that are the source of information upon which the decisions are made. The data are filtered through many offices before they arrive at the top-level decision maker's desk. At best, the truth has been presented; at worst the information is false and larded with willfully misleading impressions. A single misleading message can spark a wrong decision from an otherwise accurate collection of data.

A great deal of energy is devoted to acquiring, recording, and disseminating information as factually as possible. This effort amounts to a production process in which the product is information. Raw materials are bits of data. They are received and inspected for accuracy. Bits from several sources are assembled. Some are stored as inventory in files or data banks for later use, and others are packaged for shipment as memos or reports. The shipping lines are the communication channels in and among organizations. Whoever has requested the information is the consumer to be satisfied. Like other products, information may be rejected due to inferior raw materials, careless assembly, unattractive packaging, or staleness caused by delays in distribution.

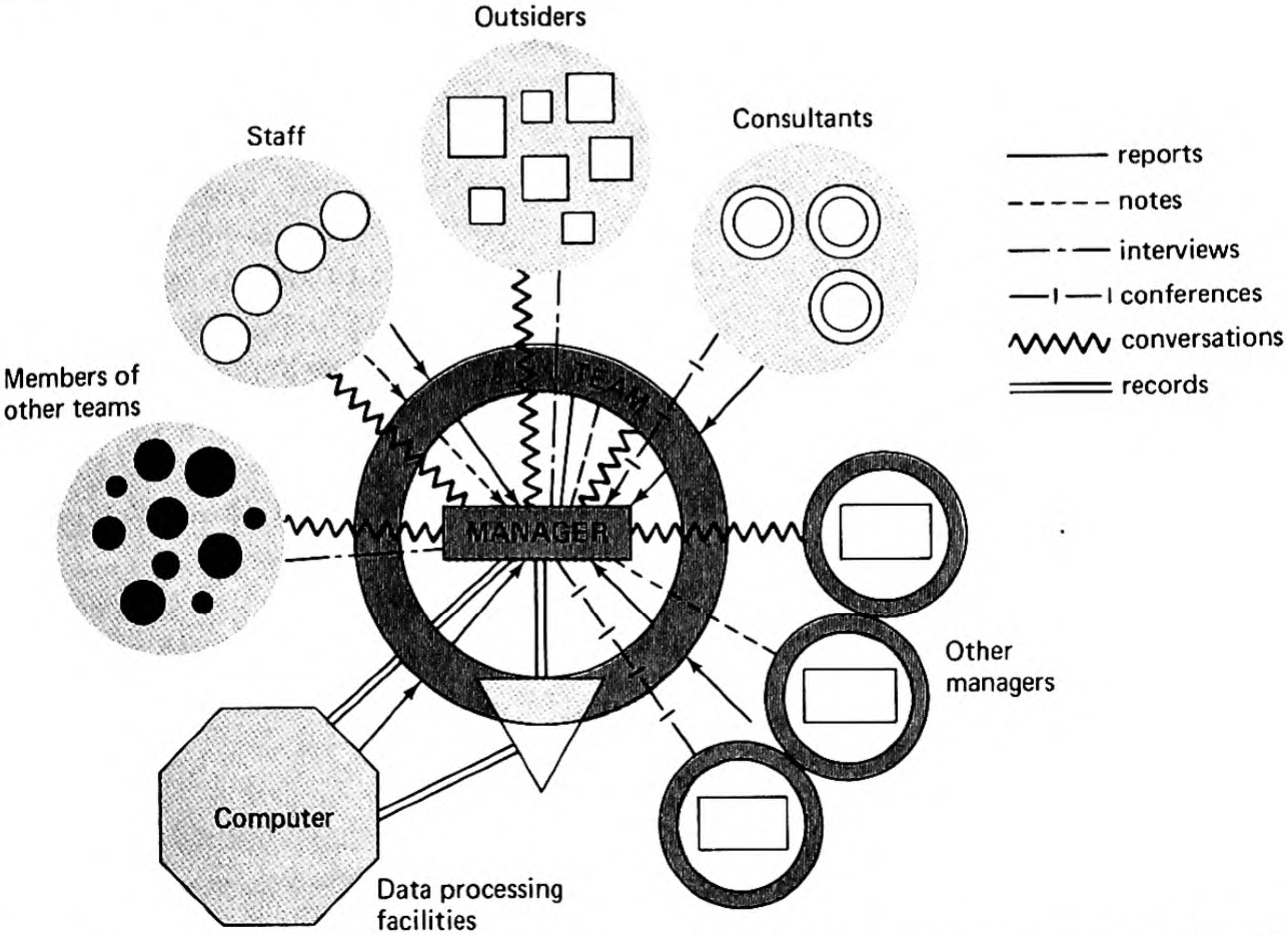

Outsiders
Staff
Consultants
reports
notes
interviews
conferences
conversations
records
Members of other teams
TEAM
MANAGER
Other managers
Computer
Data processing facilities

*Fig. 10-3. A manager taps many sources of information, using several channels. The length of the channels and the filtering effect increase for higher levels of management. Some information passes through the manager's immediate team and other data go directly to him. His sources of data are both inside and outside his own organization.*

The distribution aspect of information is closely related to the coordination of activities. A leader relies on communication from his team to keep track of progress and to anticipate problems. Information about the current situation comes to the leader from above and from his contacts within and outside his group. These channels of information are represented in Figure 10-3. For convenience of discussion we can divide the channels into two categories: person-to-person and machine-assisted. "Person" channels vaguely follow the lines in an organization chart (see Chapter 3); messages flow downward for commands, sideways for coordination, and upward with operating information or appeals. "Machine" channels are more closely aligned with operating functions; messages flow to a centralized depot where they are stored for reference or consolidated to facilitate future planning and control.

### Person-to-Person Communications

Individuals transmit messages to each other verbally and in writing. While conducting business, the sender seeks to *inform* or *sell* and the receiver *collects* and *evaluates*. The message can be garbled at either end or by the medium of transmission. For instance, a long-distance phone call could deliver an inaccurate message if the caller talked too fast to be understood. Static in the lines might mask some words. Or, the listener might be too distracted by other events to give full attention to the call.

The mechanical factors in person-to-person communication can be improved by training. "Charm schools" stress the importance of proper pronunciation, pace, posture, and style in speaking. Perhaps the most enlightening way to check your own verbal ability is to record and study one of your presentations; it can be a very sobering experience. Training in written communications ranges from grade school lessons on penmanship and grammar to college-level information theory courses. A report should be written with a high degree of craftsmanship; it is an individual's knowledge and personality committed to paper.

Many communication barriers are raised by personal reactions to different situations. Here are some factors affecting face-to-face interviews which have their counterparts in other forms of communication.

**FAILURE TO LISTEN.** Throughout our lives we are urged to do things in a given way. Advertisers pressure us to buy certain products. Parents, teachers, and well-meaning friends urge us to conform to a certain pattern. We naturally build defenses to these entreaties; we do not give everything we hear the same attention. The result is that listeners often tend to hear only things that fit their purpose and then shut out the rest of the message, while deciding what they are going to say in reply.

**FAILURE TO RELATE.** People realize that in business situations there is usually a purpose behind any contact. The reasons for the contact are not necessarily mutually compatible. Therefore, the skilled sender and the skilled receiver may duel with words, probing here and there to find the most effective way to deliver a message. Each side codes the other's intentions in terms of his own interests and the other person's motives. The result is that either or both sides fail to get their point across: an engagement without an actual exchange of information.

**FAILURE TO LEVEL.** Most business interviews involve parties from different organizational levels. When one party is subordinate to the other, he may be reluctant to speak his real opinions. The fear of reprisal, though distant, can cause a subordinate to parry questions that appear sensitive to his personal interests and those of his associates. The same defensive attitudes can block effective exchanges between people on the same organizational levels if their spheres of influence overlap or their activities are competitive.

### Information-Processing Machines

Information technology has recently increased at a rate that makes progress in mechanical technology seem a snail's pace by comparison. The automation of data processing has not received the criticism aimed at automated assembly processes; it has had, however, a comparable effect on society. Greater capacity, speed, and convenience of automated data-processing hardware, plus improved data management, has allowed the collection and use of information in ways not formerly possible. Sociologists have expressed fear that the accumulation of information about people's personal histories has reached the level of invasion of privacy. This ethical issue, however, is related more to social records, and is not important in most business applications. Here the data-digesting and process-control capabilities of machines are openly praised as indispensible services.

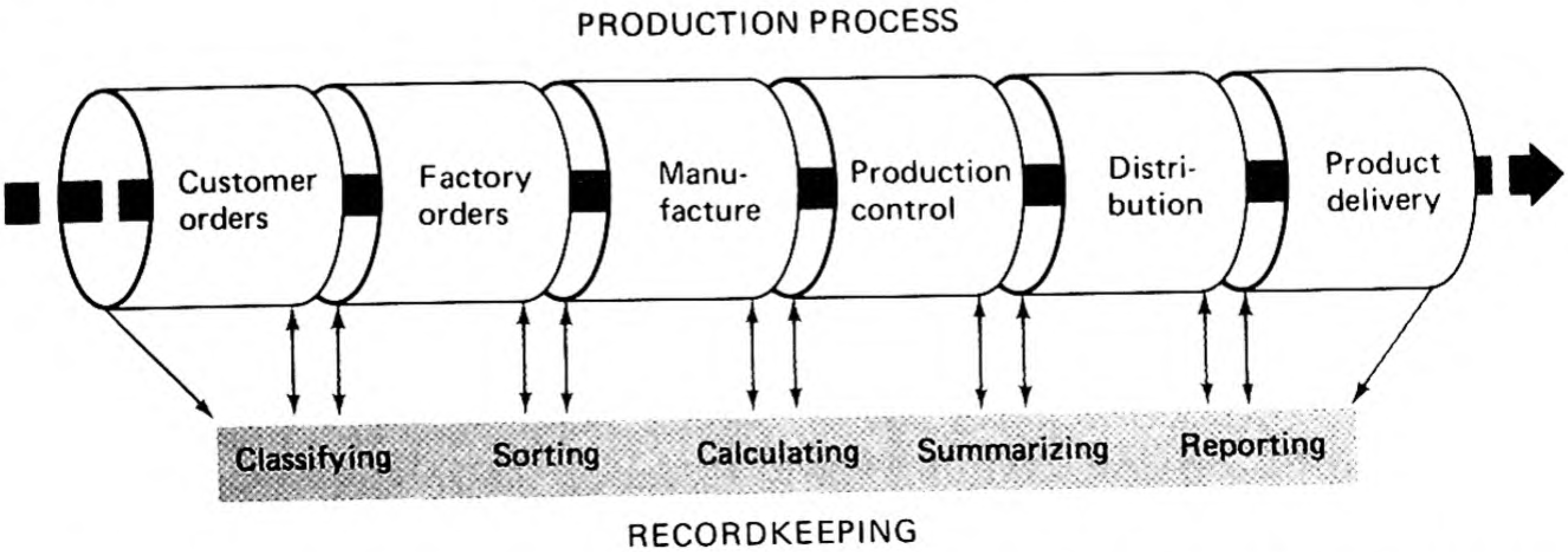


*Fig. 10-4. Records provide information to coordinate activities throughout all phases of the production process.*

As depicted in Figure 10-4, record-keeping activities stretch through all phases of a manufacturing process. These records provide the information needed to coordinate the activities of men and machines. Inaccurate or late information can reduce output with the same finality as faulty material or delinquent operators.

The availability of immensely capable machines is not enough to ensure the information flow required to coordinate events. The machines have to be programmed and serviced to perform their intended function. Their ability to store huge quantities of data with instant recall is of no practical value if the needed facts have not been stored or if the stored information is inaccurate. Even if the right information is stored, it serves no purpose until it is retrieved from the data banks and forwarded to the person who needs it. Then there is the opposite problem: managers being overwhelmed by so much data that they lack the time to evaluate its pertinence. The almost unlimited capacity of machines to record, store, and move information proves an irresistible temptation to some data-processing directors. A few yield to the lure by increasing the data flow as proof of their value to the organization.

The problems of having the right information in the right amount available at the right time at the right place have led to the concept of a *management information system* (MIS). Walter Kenneron defines MIS as "an organized method of providing past, present and projection information relating to internal operations and external intelligence. It supports the planning, control and operational function of an organization by furnishing uniform information in the proper time-frame to assist the decision maker." ("MIS Universe," *Data Management*, September, 1970.) The goals of MIS are impressive, and considerable progress has been made toward developing one integrated system to handle all the information needs of some organizations. Although a management information system could theoretically operate manually, most significant applications are computer-based. When such centralized systems are fully operational, they should provide unprecedented logistic assistance. And coordination will benefit accordingly.

## INVENTORY MANAGEMENT

A large amount of information generated by an enterprise concerns materials used by the organization. Many of the early applications of computers were aimed at keeping better records for inventory control. Even firms that produce a service instead of a product have to pay close attention to inventory records to avoid running out of supplies. When needed items are unavailable, a service firm must delay service or use substitute items that are more expensive or inferior; both situations detract from the quality of service and will eventually ruin a firm's reputation if continued.

Material flow in a manufacturing organization is a critical and expensive issue. All the record-keeping functions shown in Figure 10-4 can be associated with the flow of materials through a production process: purchasing raw materials, procuring parts and supplies, storing material, keeping track of in-process stocks, warehousing products, and distributing finished goods. Data are required at every stage to keep the process moving. Without adequate information the product flow can be disrupted and decision making will suffer from lack of sufficient or timely data.

The work activities of employees concerned with inventories and the associated flow of information are easy targets for coordination. The passage of raw materials and products through an organization is open evidence that workers are accomplishing their tasks and that messages are getting through. There is a less evident aspect of material flow that also serves a vital function in coordination. It involves the way material is used as a buffer between work operations.

Innumerable annoying difficulties occur while a work plan is carried out, no matter how conscientiously it was developed. The cumulative effect of these difficulties is a series of lags and spurts in progress. For the first in a series of operations in a process, the stalls and surges of output are not too serious. It is the downstream operations where the effects are magnified. Anyone who has waited in a backed-up stream of traffic caused by the magnified effects of just one traffic light has experienced first hand this effect. Industry, however, often has "buffers" or reservoirs of stock in between successive stages of an operation. These buffers keep the operation from being alternately idle from lack of work and inundated by too much work.

Stockpiles of materials at key stages of a process are maintained to decouple each stage from its dependency on related operations. This reserve of materials can be tapped whenever the input flow is curtailed from a prerequisite operation. Oppositely, the reserve can absorb upstream inputs when downstream operations are not functioning properly. The way inventory insulates the stages of a process is represented in Figure 10-5.

Besides insulating stages of progressive product development, inventory policies are also key considerations in total planning. Employment can be stabilized by accumulating and storing raw materials, such as farm crops, while they are in season, to spread processing over several months.

In the grape-juice industry, processers using additional help run their juice-extracting operations around the clock when the fruit is ripe in the fall. This fresh juice is stored under conditions which will preserve its freshness. Then through

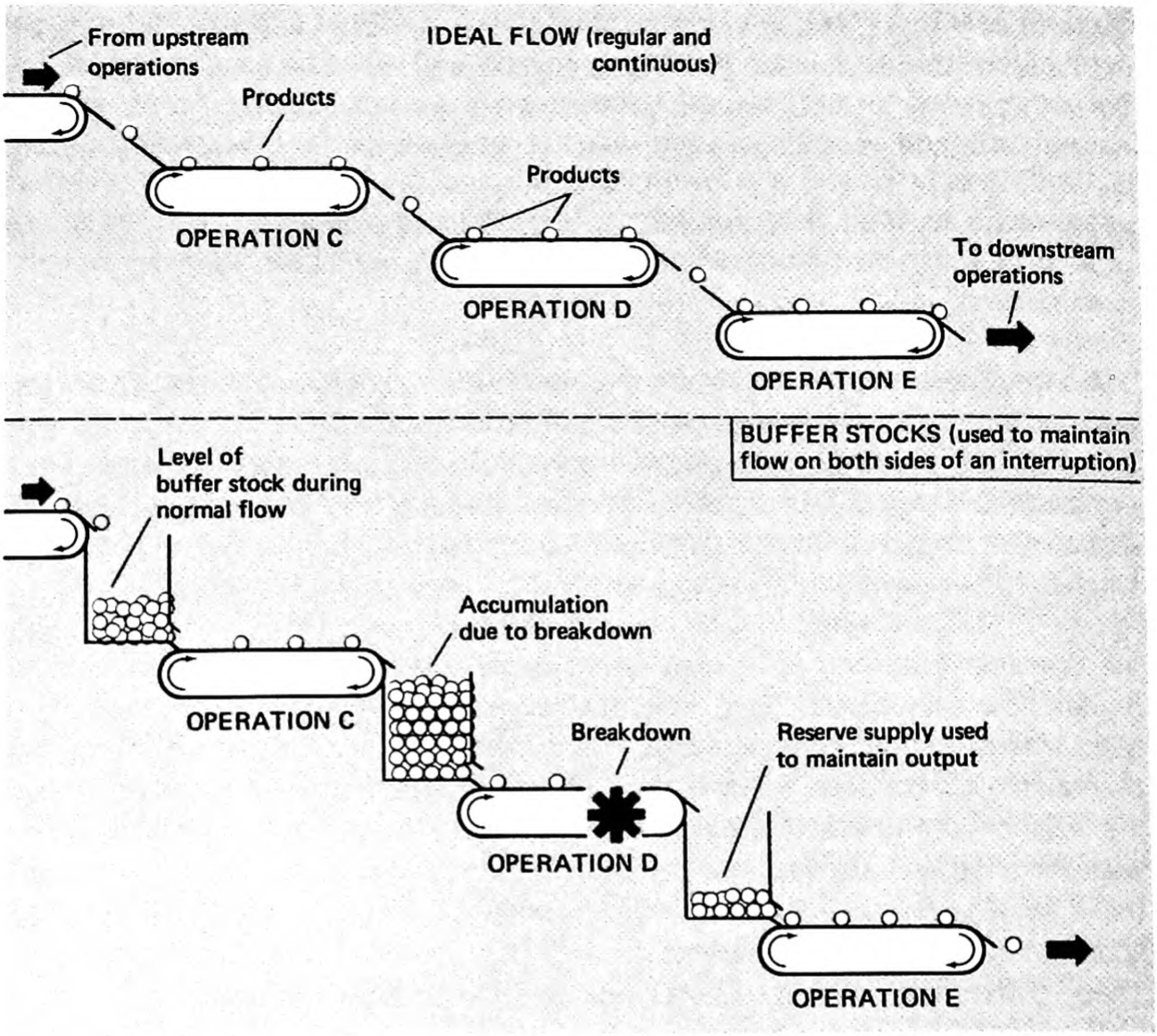

From upstream operations
IDEAL FLOW (regular and continuous)
Products
Products
OPERATION C
OPERATION D
To downstream operations
OPERATION E
BUFFER STOCKS (used to maintain flow on both sides of an interruption)
Level of buffer stock during normal flow
Accumulation due to breakdown
OPERATION C
Breakdown
Reserve supply used to maintain output
OPERATION D
OPERATION E

*Fig. 10-5. Most production processes and many service functions exhibit progressive stages of product development—refinements made at successive stages to produce a finished product. Men and machines perform specialized operations at each stage. When the flow from prior stages is disrupted, they are idled by the stoppage unless items from those stages have been stockpiled as shown for operation E. Similarly, operation C is not stalled by the breakdown in operation D because output is stored between C and D.*

winter and spring months, they return to regular work force and process the stored juice into jellies, grape juice, and wines. Similarly, finished products, such as swim suits or ski equipment, can be produced at an even pace and stored until the demand period arrives. By such inventory buildups, a relatively stable work force can be maintained. Efficiency at this constant employment level is greater because more accurate scheduling can be done when supply and demand conditions are known reasonably well. Community relations and general morale also benefit from the absence of frantic hiring during rush periods and intermittent layoffs during unstable seasons.

The advantages gained from reserving materials are not obtained without cost. Raw materials may rot before they can be used. Bulk purchases of components may be made technologically obsolete before they are needed in assemblies.

Unfinished items stored between production stages can be damaged, lost, or stolen. Space has to be provided for storage. Special conditions such as refrigeration may be required. Guards, janitors, storekeepers, material handlers, recordkeepers, and others are needed to service the inventories. Not all these costs apply to every article, of course, but enough do apply to make inventory policy a fertile field for economic analysis.

An inventory policy is similar to an insurance policy. A buffer stock ensures against running out of material. How much to hold in reserve depends on the likelihood of distruptions in supply or demand. This uncertainty can be evaluated in much the same way risk tables are used to calculate the cost of theft or fire insurance. Some costs are difficult to quantify in the same way that pegging a dollar value on the pain caused by an accident is difficult. The preferred inventory policy balances the cost of loss from lack of resources with the cost of maintaining the idle resource.

### Basic Cost Categories

Rules of thumb for inventory control have probably been around as long as there have been shopkeepers. Some formulas for deciding *when* and *how much* to order were developed early in this century. With the availability of better information systems from the 1940s onward, many refinements have been made in the mathematical analysis of inventory policies. In this section we will consider just the basic cost categories: carrying costs and ordering costs.

The expenses classified as *carrying costs* include all outlays, real and theoretical, associated with holding materials. Carrying costs differ according to the characteristics of the material. Estimates based on experience are made for cost components in the following categories:

1. **STORAGE.** Total cost of providing storage room. If space is leased, storage costs include the rent, material handling, and necessary records. When the storage facilities are owned, each type of material is charged with a prorated share of building depreciation and taxes, supervisory and operating personnel, material handling equipment, and special costs such as guards or heating.

2. **INSURANCE.** Amount paid for insurance on the material itself.

3. **TAXES.** Assessments placed by some localities on the amount of inventory on hand at a certain date or on the average investment in inventory during the year.

4. **OBSOLESCENCE.** A loss in value of stored items caused by technological advances that make them outdated or changes in style that make them outmoded.

5. **DETERIORATION OR DAMAGE.** Decrease in value caused by rough handling, aging, exposure to weather, decay, and other conditions that destroy quality.

6. **CAPITAL.** A form of "opportunity cost" in which the inventory is charged with the interest that would have been earned if the money invested in stored material had been invested to produce income. Another way of looking at this somewhat theoretical cost is that a firm might have to borrow money for operating expenses because its capital is committed to inventory; thus part of the cost of inventory is the charge for using borrowed money. This "foregone investment opportunity" is then considered a cost of holding material.

The first three components are relatively easy to determine. Obsolescence, deterioration, and damage costs can be estimated from experience. The interest on money invested in inventory is usually calculated at the going interest rate at which the firm could borrow funds from a commercial source. As an example of the pattern of carrying costs, consider the following categories:

- Storage = 2 cents per item per year
- Insurance = 0.1 percent of the item's value per year
- Taxes = 0.4 percent of the item's value annually
- Obsolescence and deterioration = 1.5 percent of the item's value per year
- Capital = 8 percent per annum based on the item's value

It is apparent that some of the categories are based on a flat charge per unit and others reflect the value of the item being stored. If the unit price is \$4.00, its carrying cost would be $\$0.02 + (0.1\% + 0.4\% + 1.5\% + 8\%)(\$4.00) = \$0.02 + (0.10)(\$4.00) = \$0.42$ per year.

Often all of the carrying cost categories are combined into one percentage factor based on the worth of the inventory item or a single flat charge per item. Letting the symbol $i$ represent the percentage factor, we have for the example above $i = \dfrac{\$0.42}{\$4.00} \times 100\% = 10.5\%$. Then the cost of holding one unit in storage for one year is $H = Pi = \$4.00 \times 10.5\%$, where $H$ is the total carrying cost and $P$ is the unit price. As we use $H$ in calculations designed to minimize inventory costs, it is important to remember the relationships of the cost categories comprising $H$. In the sample computations on the following pages, $H$ is assumed to be \$0.115. This flat charge figure is the sum of all the individual carrying-cost categories expressed as a single charge for holding one item in stock for one year.

*Ordering costs* are the expenses incurred from placing an order for material with an outside vendor or with another department within the organization. When material is purchased, purchase orders must be prepared, invoices processed to pay the vendor, and the lots received must be inspected and delivered to the storage or process areas. For material available within the firm, ordering costs again include the paperwork for requisitioning and payment. In addition, the department which has ordered the material is charged with the vending department's *setup costs*—expenses associated with starting a new production run which include adjusting machines to produce the ordered items and scrap created by the first items produced during the start-up.

The magnitude of the ordering costs for each type of material is usually determined by the purchasing department and accounting department. For a given type, the ordering costs per order will vary slightly according to the amount ordered, but the variance is normally not significant and is therefore ignored in most inventory models.

### Basic Inventory Model

We have already observed how a mathematical model only approximates reality. Many simplifying assumptions are made for the sake of workability. The basic inventory model, called the *economic order quantity* (EOQ) formula, is no exception. Though many of the relationships used in calculating the EOQ are

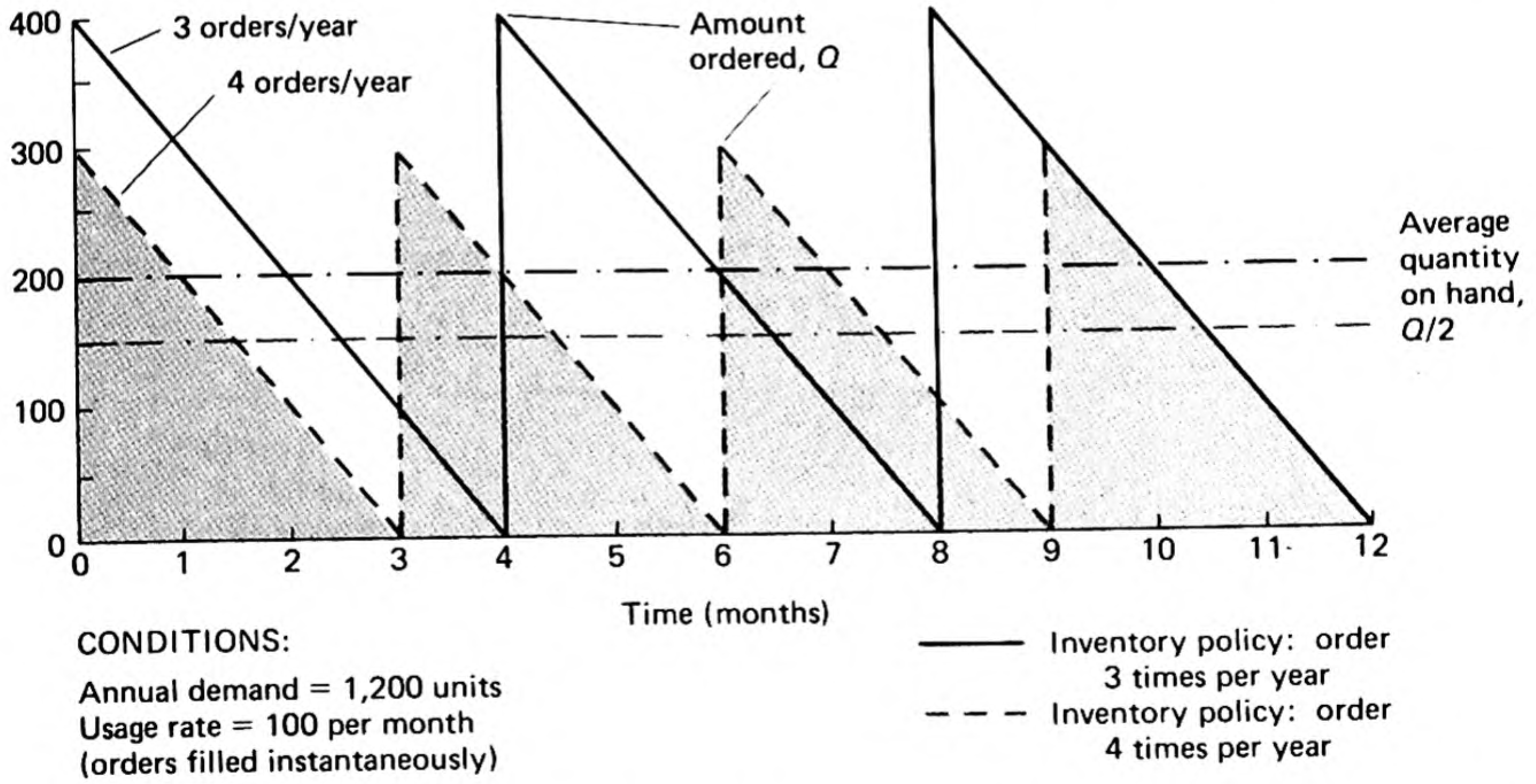


*Fig. 10-6. Idealized pattern of material usage and replenishment. In reality, the usage rate for material is seldom constant (straight sloping lines) and the replenishment is never instantaneous (vertical lines). However, a straight line is a reasonable approximation of usage that varies slightly above and below the line. Also by replacing orders before inventory levels reach zero, replenishment is in effect instantaneous because a new order is delivered close to the time the supply on hand is exhausted.*

idealized, it still provides reasonably accurate figures for practical applications. A host of more refined models are available for closer representations of actual conditions. However, the cost of attaining greater reality in models must be paid in added mathematical complexity.

The economic order quantity is the size of order which minimizes the cost of acquiring and holding an inventory item. The ordering cost and carrying cost vary inversely with each other. That is, when a large order is placed, the ordering cost goes down while the carrying cost increases. The reason is easy to see in Figure 10-6. In the situation shown, one inventory policy is to order material three times a year. Thus ordering costs occur three times. In the other inventory policy shown, four orders are placed to obtain the same amount of material annually. By placing four orders instead of three, the amount ordered each time, $Q$, is less. A smaller $Q$ yields a lower average inventory, $Q/2$. Since total carrying costs are a function of the average inventory, and total ordering costs depend on the number of times orders are placed, the cost of carrying decreases when the cost of ordering increases.

From Figure 10-6 it is apparent that when the annual demand is known, a policy to place an order of size $Q$ establishes how many times a year an order is placed. If we let the symbol $O$ indicate the ordering cost per order and $D$ indicate the annual demand, then the total annual ordering costs equal $OD/Q$.

By letting $H$ indicate the cost to hold one item in stock for a year, the expression for the total annual carrying costs is $HQ/2$. Note that $Q/2$ is the average number of items on hand. To check this value we can look at Figure 10-6 to get the inventory level at the middle of each month. Using one cycle of the four orders-per-year pattern, we find

| **Month** | **Inventory Level At Mid-month** |
|---|---|
| 1 | 250 |
| 2 | 150 |
| 3 | 50 |
| Total: | 450 |

$$\text{Average stock level for a 3-month period} = \frac{450}{3} = 150$$

or, equivalently,

$$\frac{Q}{2} = \frac{300}{2} = 150$$

Adding the two cost expressions gives us the total basic inventory cost: $OD/Q + HQ/2$. To find the economic order quantity, we can use trial and error tabulation, graphing, or algebra. To illustrate each of these methods, they will be applied to a problem in which

$D$ = annual demand = 20,000 units
$O$ = ordering cost = \$46.00 per order
$H$ = carrying cost = \$0.115 per unit

A tabular solution is shown in Figure 10-7. The EOQ is indicated by the lowest cost in the bottom row which appears when five orders are placed each year. Note at this point the carrying costs equal the ordering costs.

| (1) Number of orders per year | 1 | 2 | 4 | 5 | 6 | 10 | 20 |
|---|---|---|---|---|---|---|---|
| (2) Order quantity: 20,000 (1) | 20,000 | 10,000 | 5,000 | 4,000 | 3,333 | 2,000 | 1,000 |
| (3) Carrying cost: \$0.115 × (2)/2 | \$1,150 | \$575 | \$288 | \$230 | \$192 | \$115 | \$58 |
| (4) Ordering cost: \$46 × (1) | \$46 | \$92 | \$184 | \$230 | \$276 | \$460 | \$920 |
| (5) Total annual cost: (3) + (4) | \$1,196 | \$667 | \$472 | \$460 | \$468 | \$575 | \$978 |
| | | | | EOQ | | | |

*Fig. 10-7. Trial and error method of solving for the EOQ. Given annual demand, carrying cost per unit, and ordering cost per order, the order quantity is determined by dividing the annual demand (20,000) by the number of orders per year. Then the total carrying costs equal half this value, multiplied by \$0.115. Total ordering costs equal \$46 times the number of orders per year. Total basic inventory cost is the sum of the ordering and carrying costs. Calculations are continued until a minimum point is identified, the EOQ.*

The graph in Figure 10-8 displays the same information given in Figure 10-7. Total ordering costs decrease as the size of the order increases, while total carrying costs climb for the same conditions.

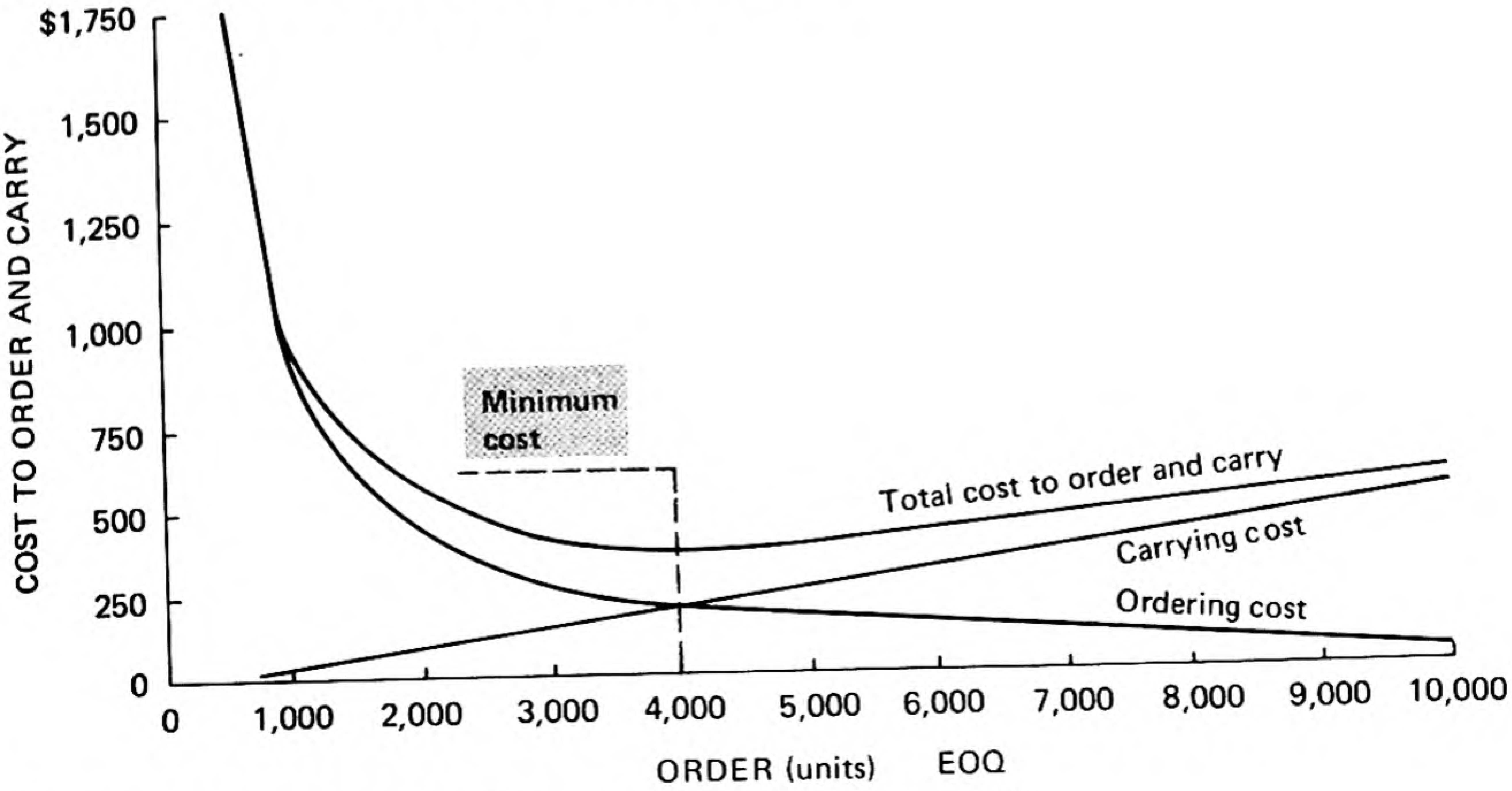


*Fig. 10-8. A graph to identify the economic order quantity.*

The easiest way to determine the EOQ is with a formula. The foundation of the formula comes from recognizing the cost relationship shown in Figure 10-7: carrying costs equal ordering costs at the EOQ. Using the same symbols for the inventory factors, we have ordering cost equals carrying cost (at EOQ)

$$O\frac{D}{Q} = H\frac{Q}{2}$$

where $D$ = annual demand = 20,000 units
$O$ = ordering cost = \$46.00 per order
$H$ = carrying cost = \$0.115 per unit
$Q$ = order quantity

Rearranging the equation to collect the order quantity symbols, $Q$, on one side,

$$OD = \frac{H}{2}Q^2 \qquad \frac{2OD}{H} = Q^2$$

and then taking the square root of both sides produces

$$Q = \sqrt{\frac{2OD}{H}}$$

which is the formula for the EOQ.

The correctness of the formula is confirmed by substituting the values applied in Figures 10-7 and 10-8 for the formula symbols;

$$Q = \sqrt{\frac{2 \times \$46 \times 20{,}000}{\$0.115}} = \sqrt{\frac{\$1{,}840{,}000}{\$0.115}}$$

$$Q = \sqrt{16{,}000{,}000} = \underline{4{,}000 \text{ units} = \text{EOQ}}$$

which, of course, agrees with the tabular and graphic solutions.

By manipulating the basic equation, we can calculate several other conditions associated with the EOQ:

$$\text{Basic annual inventory cost} = O\frac{D}{Q} + H\frac{Q}{2}$$

$$= \$46\frac{20{,}000}{4{,}000} + \$0.115\frac{4{,}000}{2}$$

$$= \$230 + \$230 = \$460$$

$$\text{Optimum number of orders per year} = \frac{D}{Q} = \frac{20{,}000}{4{,}000} = 5 \text{ orders}$$

$$\begin{array}{c}\text{Optimum order interval}\\ \text{(calendar days between orders)}\end{array} = \frac{365 \text{ days/yr}}{\dfrac{D}{Q}} = \frac{365 \times Q}{D} = 73 \text{ days}$$

### Refinements to the Basic Inventory Model

Assumptions included in the basic inventory model limit its accuracy. The $Q = \sqrt{\dfrac{2OD}{H}}$ equation produces a quick, in-the-right-ballpark answer that is

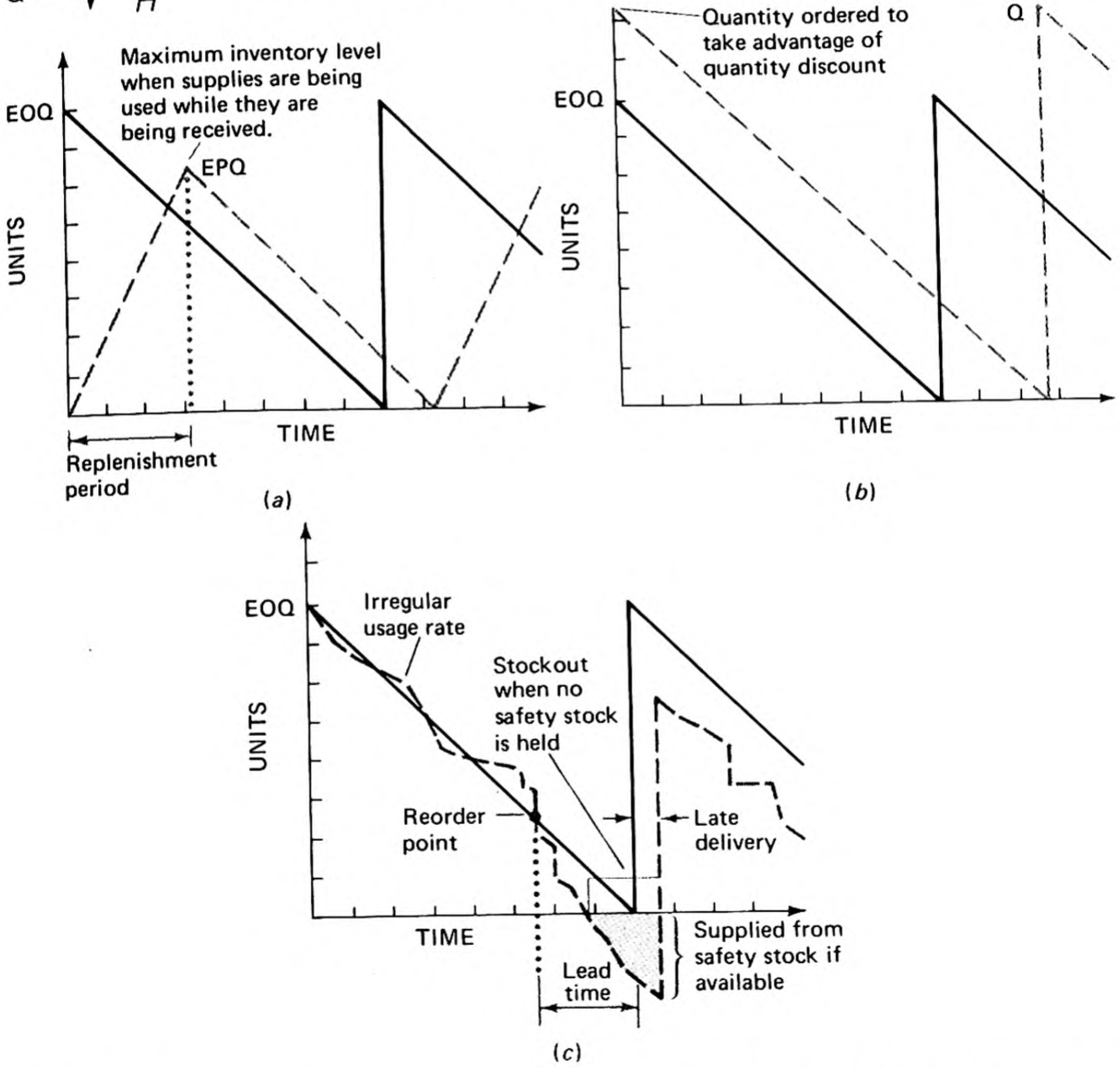


*Fig. 10-9. Variations in inventory pattern (dashed lines) compared with the idealized pattern (solid lines). (a) After ordering, supplies are received regularly during a replenishment period rather than in one shipment. The amount ordered is the economic production quantity, EPQ; (b) increasing the order size above the EOQ may reduce total inventory costs when price discounts are received for large orders; (c) inventory may not be used at a constant rate. When the usage rate is higher than expected after placing an order, a stockout will occur unless a safety stock has been provided. Late delivery also causes a stockout.*

satisfactory for situations in which rough estimates serve the purpose. However, there are other occasions when the costs involved make it worthwhile to investigate the inventory pattern more closely. We will now consider ways to relax the three assumptions included in the idealized pattern of Figure 10-6. These modifications are shown in Figure 10-9.

**ECONOMIC PRODUCTION QUANTITY.** Finished goods are often received at a steady rate rather than in one shipment. Then the items received are used or sold during the replenishment period. This pattern is common when one division of an organization receives its supplies from another division of the same firm.

The basic EOQ formula is modified to represent a replenishment period, rather than instantaneous replenishment, by adding a term to account for the replenishment rate:

$M$ = *manufacturing rate* = annual output of the item
being produced or supplied

This term affects the carrying costs because the maximum inventory level is always less than the amount ordered when supplies are being used as they are being received. Therefore, the charge for holding inventory in a situation of steady replenishment is lower than that for instantaneous replenishment.

The use-as-you-get relationship can be explored by returning to the conditions for the EOQ calculations previously conducted; with $O = \$46$, $D = 20{,}000$ units, and $H = \$0.115$, the EOQ was 4,000 units assuming instantaneous replenishment. Now assume the order is produced at the rate of 500 per day and there are 200 working days per year:

$$M = 500\,\frac{\text{units}}{\text{day}} \times 200\,\frac{\text{days}}{\text{yr}} = 100{,}000 \text{ units annually}$$

The replenishment period is

$$\frac{Q}{M/200} = \frac{4{,}000}{100{,}000/200} = \frac{4{,}000}{500} = 8 \text{ working days}$$

Each day during the replenishment period the usage rate is 20,000/200 = 100 units, assuming 200 working days per year.

Then the inventory level increases at a rate of

$$\frac{M}{200} - \frac{D}{200} = 500 - 100 = 400 \text{ units per day}$$

The maximum inventory level is reached at the end of the replenishment period:

$$\text{Maximum stock level} = \left(\frac{M}{200} - \frac{D}{200}\right)\left(\frac{Q}{M/200}\right) = (M - D)\left(\frac{Q}{M}\right)$$

$$= (100{,}000 - 20{,}000)\left(\frac{4{,}000}{100{,}000}\right)$$

$$= (80{,}000)\,(0.04) = \underline{3{,}200 \text{ units}}$$

This number, 3,200, is 20 percent lower than the 4,000 level for maximum in-
Total inventory cost at $Q = 4{,}000$

It follows that the expression for average inventory is

$$(M - D)\,\frac{Q}{2M} \qquad \text{or, equivalently,} \qquad \left(1 - \frac{D}{M}\right)\frac{Q}{2}$$

which establishes the relationship for steady replenishment that

$$\text{Carrying cost} = H\,\frac{Q}{2}\left(1 - \frac{D}{M}\right)$$

Since the ordering cost retains the same relationship irrespective of the way the order is delivered, the basic inventory cost for units produced as they are used is

$$\text{Ordering cost} + \text{carrying cost} = O\,\frac{D}{Q} + H\,\frac{Q}{2}\left(1 - \frac{D}{M}\right)$$

Again the minimum cost inventory policy is obtained by equating the two costs and solving for Q. The value of Q thus derived is called the *economic production quantity,* EPQ, and

$$EPQ = \sqrt{\frac{2OD}{H(1 - D/M)}}$$

Applying this formula with the values used previously, we get

$$EPQ = \sqrt{\frac{2 \times \$46 \times 20{,}000}{\$0.115\left(1 - \dfrac{20{,}000}{100{,}000}\right)}} = \sqrt{\frac{1{,}840{,}000}{0.115(1 - 0.2)}}$$

$$= \sqrt{20{,}000{,}000} = \underline{4472 \text{ units}}$$

**QUANTITY DISCOUNTS.** Vendors frequently encourage larger orders by lowering the per unit price of the items when an order exceeds a certain minimum quantity. A supplier can afford such price discounts because he saves on transportation costs, selling expense, and economies achieved from longer production runs. The buyer also saves because he has fewer orders to place, a lower purchasing price, and less chance of running out of stock if demand is unusually high. The buyer, however, also must assume higher carrying costs if he orders a quantity greater than the EOQ.

The easiest way to evaluate the merit of a quantity discount proposal is to calculate the total inventory cost with and without the discount. Once more using the data that led to Figure 10-6, let us assume a vendor will supply the units at a 5 percent discount if the order size is 10,000 units or more. Further assuming that the price for one unit is $1.00 without the discount, we can calculate the total annual inventory cost when the quantity ordered is 4,000 units, the EOQ:

$$\text{Total inventory cost} = O\frac{D}{Q} + H\frac{Q}{2} + DP, \text{ where } P = \text{unit price}$$

$$\text{Total inventory cost at Q} = 4{,}000 = \frac{\$46 \times 20{,}000}{4{,}000} + \frac{\$0.115 \times 4{,}000}{2} + 20{,}000 \times \$1$$

$$= \$230 + \$230 + \$20{,}000 = \$20{,}460$$

Recognizing that the lowest cost strategy for using a quantity discount usually is to place the minimum-size order that qualifies for the discount, we find

Total inventory cost at $Q = 10{,}000$ and $P = \$0.95$ per unit

$$= \frac{\$46 \times 20{,}000}{10{,}000} + \frac{\$0.115 \times 10{,}000}{2} + 20{,}000 \times \$0.95$$

$$= \$92 + \$575 + \$19{,}000 = \$19{,}667$$

Note that if the holding cost was expressed as $H = Pi$ instead of the flat $0.115 charge, then the value of $H$ would vary with the change in unit price.

Although the carrying cost increased by 250 percent for an order size of 10,000 compared to $EOQ = 4{,}000$, the savings gained from placing fewer orders and lower buying costs verify the strategy to use the discount. We can check the possibility of placing only one order per year as

$$\text{Total inventory cost at } Q = 20{,}000 = \frac{\$46 \times 20{,}000}{20{,}000} + \frac{\$0.115 \times 20{,}000}{2}$$

$$+ 20{,}000 \times \$1.00 \times 0.95$$

$$= \$46 + \$1150 + 19{,}000 = \$20{,}196$$

Obviously for the values used in the example it is a better policy to order the minimum quantity that qualifies for the discount. Other factors also should be considered, however, such as the availability of room to store the larger quantities, greater danger of deterioration and damage, and the loss of flexibility in meeting changing market conditions.

**SAFETY STOCK.** The most unrealistic assumption in the basic EOQ formula is that a replenishment will arrive when the stock level reaches zero.

An order to replenish inventory is placed when the supply on hand drops to a level called the *reorder point*. At this point there is still a sufficient supply in storage to last until a replenishment is received, *under normal conditions*. Abnormal conditions lead to a *stockout*—a condition that exists when there is insufficient inventory to meet demand. Two circumstances are responsible for stockouts: (1) the demand is greater than expected during the time between the reorder date and the receipt of the order, (2) the order arrives later than anticipated.

Stockouts occur during the *lead time*—the actual or expected elapsed time between initiation of an order or task and its arrival or completion. The reorder point designates the beginning of the inventory lead time. In setting the reorder point, possible variations from the constant-usage, immediate-replenishment patterns are evaluated:

- Seasonal changes in demand.
- Sudden large inventory withdrawals due to major operations such as the start-up for a new project.
- A replenishment order received on time but rejected because it fails to meet quality standards.
- Partial or delayed replenishment shipments due to sudden emergencies such as weather disturbances, social strife, or political disruptions.

For established products, records may be available to determine the likelihood of experiencing different usage rates and lead times. Formulas which include costs based on the probability of these irregularities occurring are available to calculate order quantities. Such formulas, in effect, balance the stockout costs against the carrying costs for holding an inventory reserve. This reserve is called a *safety stock* or *buffer stock*—the quantity of items held in stock to absorb unusually heavy withdrawals of inventory during the lead time. When a safety stock is provided, the

Reorder point = average usage during lead time + safety stock

Questions involved in deciding the size of a safety stock are difficult to answer. In addition to the uncertainties of forecasting the extent of fluctuations in usage rates and lead times, estimating the cost of a stockout is also the problem. When a customer is turned away because the product he wants is sold out, not only the immediate sale is lost; his dissatisfaction could lead him to a competitor, perhaps permanently. Carrying costs such as damage, deterioration, and obsolescence become more critical for a reserve supply that may go untended for extended periods of time. Inventory control measures to be discussed in Chapter 11 are especially important when significant safety stocks are held.

## REFERENCE

1. Laurence J. Peter and Raymond Hull, *The Peter Principle: Why Things Always Go Wrong*, Bantam Books, New York, 1969, p. 7.

# SECTION 4
# CONTROL

A decision is the action an executive must take when he has information so incomplete that the answer does not suggest itself.

ARTHUR WILLIAM RADFORD
*Time*, 1957

Consider the control problems of an executive who heads a mighty industrial corporation. He is responsible for the big decisions that steer the entire corporation. He lacks the time to collect the facts needed to make the decisions, so he relies on other managers to supply the data. From experience or with assistance from experts he compares the level of reported progress to the level of expected accomplishment. The amount of the difference between the two levels guides his decision. Once his decision is made, the executive relies on the corporation's chain of command to implement actions to yield the expected performance. And then the cycle of control begins anew.

Far down the chain of command in the same top executive's organization is a district sales manager with a staff of five. He too makes decisions, not as sweeping as the top executive, but still vital to his realm of operations. He has the opportunity to collect facts directly in his district, yet he also relies on data from his staff. His standards of performance in terms of expected sales and costs are rigidly set and guide his operating decisions. When performance begins to drift below expectations, he personally triggers the actions needed to correct the course.

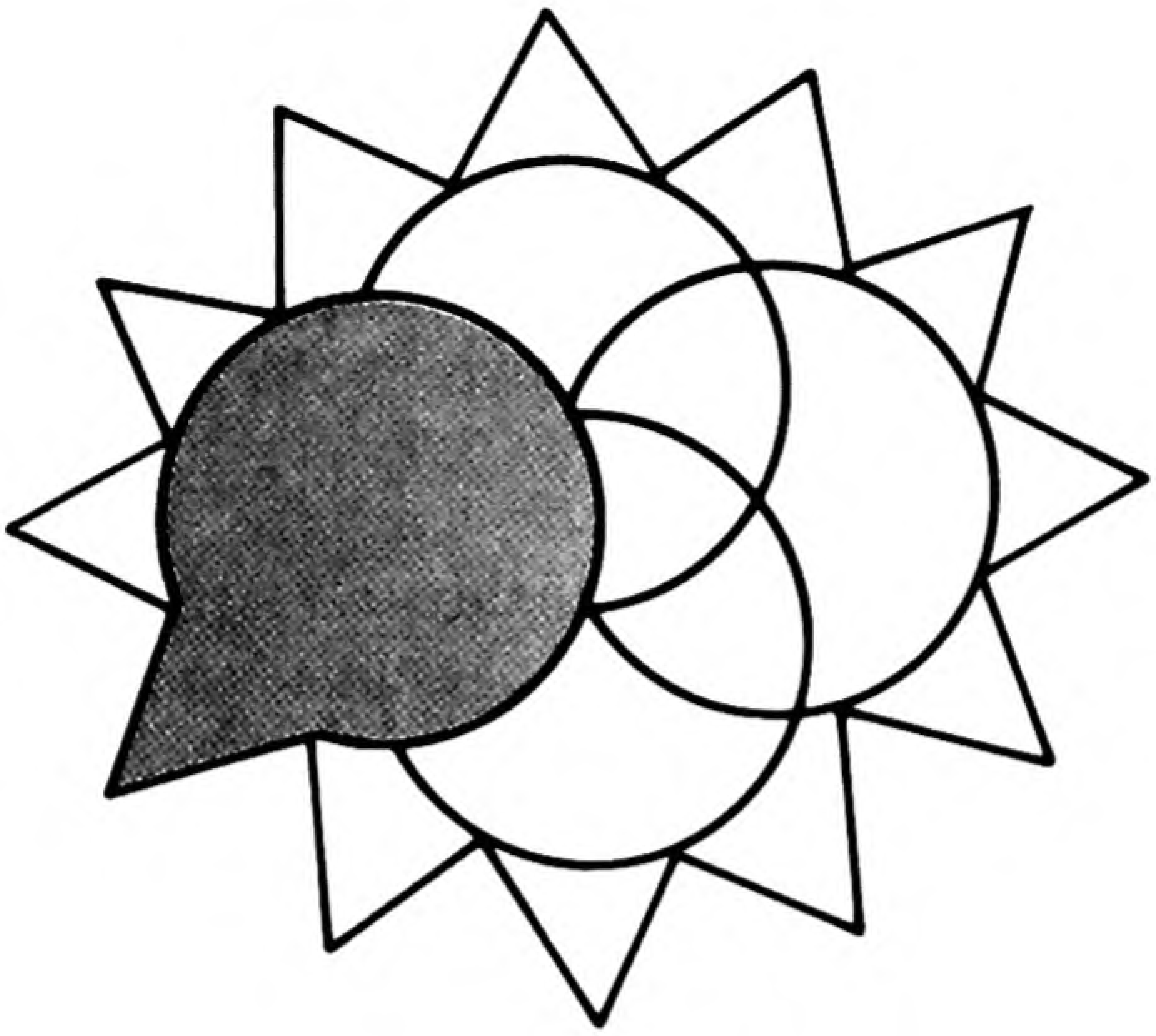
The elements of control for both the top executive and the district sales manager are essentially the same: standards—current data—comparison—corrective action. These elements link all the management functions. Standards originate from *analysis* and *synthesis*. Current data and corrective actions are part of the *conduct* function. The feature unique to *control* is feedback, the mechanism for comparing actual to planned performance. Feedback failures cause management to lose touch with reality.

In Chapter 11, "Regulating," feedback control is explored. Financial and resource ratios are presented as examples of comparison criteria. The value of charting is emphasized. The widely used management control techniques of personnel appraisal, PERT/COST, line of balance, and ABC classifications for inventory control are described.

Chapter 12, "Monitoring," focuses on quality control. A discussion of the costs and importance of quality assurance is followed by an explanation of how quality is measured. The statistical basis and examples of inspection procedures, sampling methods, and control charts are presented. Also stressed are practical considerations and special programs for the control of quality.

The last chapter in the book addresses the action most closely identified with management, "Deciding." In many ways all the previous chapters lead up to the critical subject of decision making. Significant decisions are always tough to make because there never seems to be enough information, or the information is in a form that cannot be readily used. Earlier chapters contain suggestions for overcoming lack of information. In Chapter 13 ways to include intangible considerations in evaluating alternatives are discussed, and models are presented for selecting a preferred alternative under conditions of risk. Finally, suggestions are offered to guide decision making when the outcome states are uncertain.

# Chapter 11



# Regulating

**KEY SUBJECTS**

*Management exercises its regulating function through feedback control.* A feedback loop includes a sensing mechanism to measure current performance, a monitor to compare actual to planned performance, and a means to activate future performance. Some feedback control systems are composed entirely of machines (closed systems), but most include humans (open systems). Managers have many different tools and procedures to assist their regulating duties, such as systematized methods designed to reveal what is actually happening and to compare it with what is supposed to be happening.

*Ratios of key characteristics of a system are widely used to evaluate current conditions.* Financial ratios are composed of figures drawn from financial statements and provide an indication of present economic conditions. Ratios comprised of inventory volumes indicate the success of material management. In most situations, ratios offer only a rough measure of performance. They provide a signal for the need of a detailed investigation, especially when current ratios deviate significantly from their historical patterns.

*PACE, PERT/COST, and line of balance are examples of sophisticated techniques designed to appraise, respectively, performance of support personnel,* *project costs with respect to time, and production progress on specific projects.* All three techniques are based on systematic feedback procedures and use charts for analysis and communication.

*Controls for handling and storage of materials are important to all industries and are particularly significant in manufacturing.* An ABC classification system calls attention to the small percentage of items in inventory that account for most of the dollar volume spent for materials. The three basic methods to avoid stock-outs by reordering materials at opportune times are the perpetual system, periodic system, and planned system. The principal objectives of material-handling control are to increase productivity, to improve working conditions, and to reduce costs.

## REGULATION OF DEVELOPMENTS

To regulate is to adjust or direct according to a rule. Although individuals may link the word "regulation" with red tape and bureaucratic procedures, it is a cornerstone concept for civilized behavior. Without rules and principles to guide behavior and ways to check conformance, order reverts to chaos.

Organized undertakings can be represented by the development cycle shown in Figure 11-1. The circular arrangement suggests the way the conduct of previous undertakings affects the present and guide future cycles. The three phases of development—preparation, execution, and performance—are sequentially ordered. Preparation is the initial phase in which resources are arranged. Execution involves the activities required to produce something. Performance is the accomplishment phase which results in some kind of output: a product, design, behavior, enlightenment, or need satisfaction.

The regulating function of management is linked to the development cycle by *feedback*—information extracted from a situation or system which is used to regulate future behavior or performance in that system. An individual automatically uses feedback to control his personal activities. For instance, data about current body movements are delivered from sense organs to the brain where they are transformed into directives to the muscles that control forthcoming movements. More refined feedback loops help to perform complicated mental and physical maneuvers such as driving a car or conducting a complex operation. In a similar fashion, conscious attention to feedback from the social environment allows an individual to adapt himself to the expectations of society. Feedback is thus the mechanism that supports regulation, which in turn supports the unified actions necessary for the management of teams, businesses, social agencies, and nations.

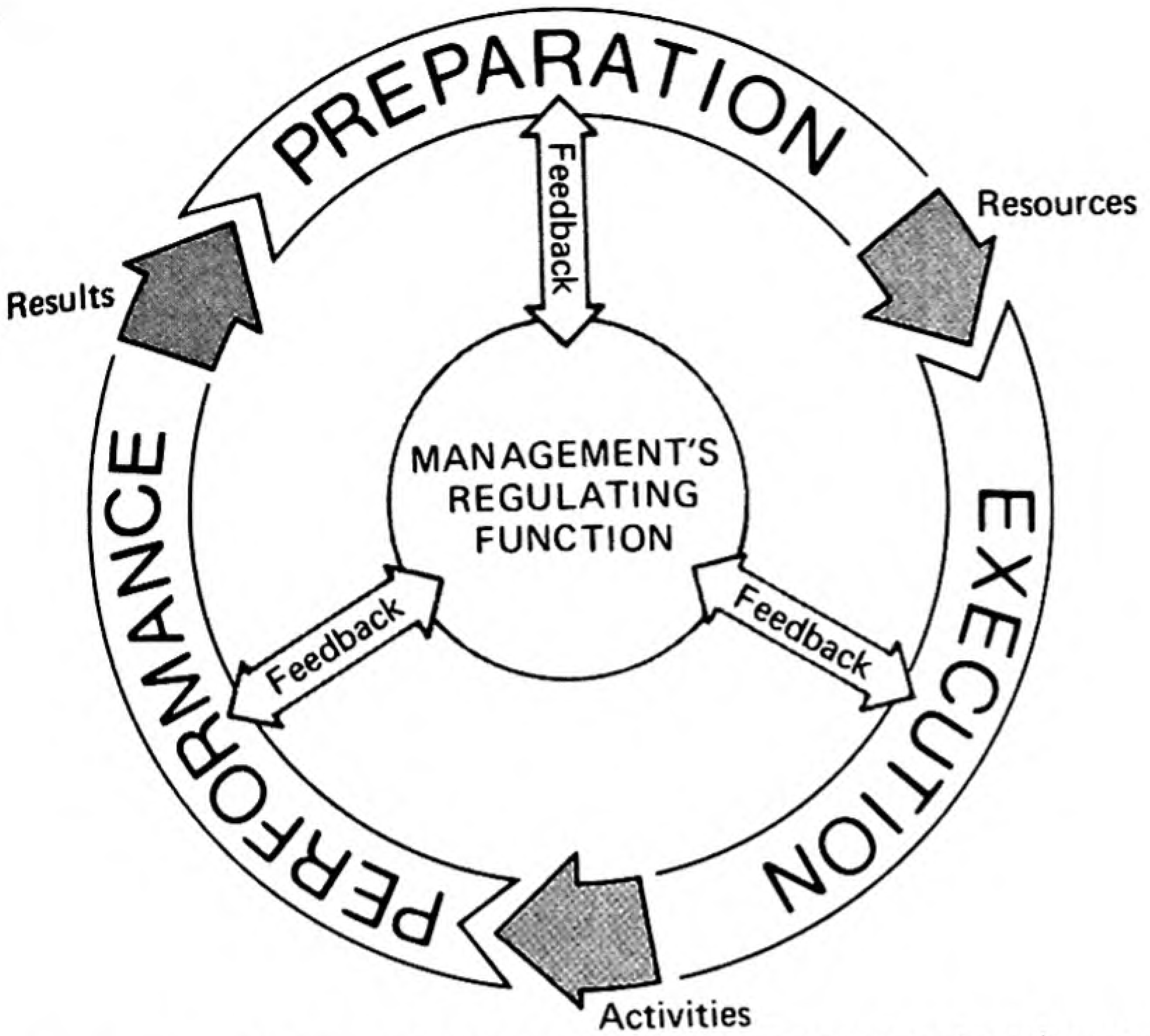


*Fig. 11-1. The development cycle. An organized endeavor begins with the preparation of resources, continues with the execution of activities, and produces some kind of results. These results are then inputs for the next cycle. Each phase of the cycle is regulated by feedback. Data about the current situation is collected by managers to guide adjustments designed to improve the final results.*

## FEEDBACK CONTROL

Most regulated systems use some form of feedback loop. Three elements are necessary for feedback control:

1. A sensing device to measure performance.
2. A monitor to compare actual performance with expected performance.
3. An activating mechanism that affects or directs performance.

A system which includes only the last item, the activating mechanism, is said to operate by *direct control*. In such systems the output conditions are established by control settings built into the mechanism. After the initial adjustment the mechanism operates according to the setting. Most small household and production machines have direct controls: fans, grinders, cutters, etc. Some processes involving people operate on essentially direct control: mailing rooms, filing sections, janitorial services, etc. The mechanism of this control is a set of directions or standard operating procedures.

In most management studies we are concerned with responsive controls which require feedback loops. We can learn about characteristics of management feedback control by investigating feedback in the more familiar heating systems used to control room temperature.

One way to heat a room is with a simple coil heater. It has a predetermined capacity and runs continuously. It is an example of direct control in a *closed system*—one that does not include a human. When a human switches the heater on or off to regulate the temperature, it becomes an *open system* with feedback control. The human acts as both the sensor and monitor; he recognizes when the temperature passes outside the comfort zone and switches the heater accordingly.

The most convenient heating system design uses a closed feedback loop as represented by the solid-line loop in Figure 11-2. The only human function is to make the initial control settings. Thereafter, performance is controlled by a switching mechanism on the heat source that responds to signals delivered from the thermostat. The setting on the thermostat determines how low the room temperature can drop before the heater is switched on and how hot the room can get before the heat source is turned off.

Elements of a management control system are comparable to the elements of the heating system. Closed feedback loops are limited by definition to systems composed of machines, but humans may be involved in the operation of the machines. For instance, output from an operation may be weighed, measured, or otherwise checked for quality by a device that is designed to return the product automatically to the responsible production source if the product fails to meet specifications. More commonly, people are involved in the feedback

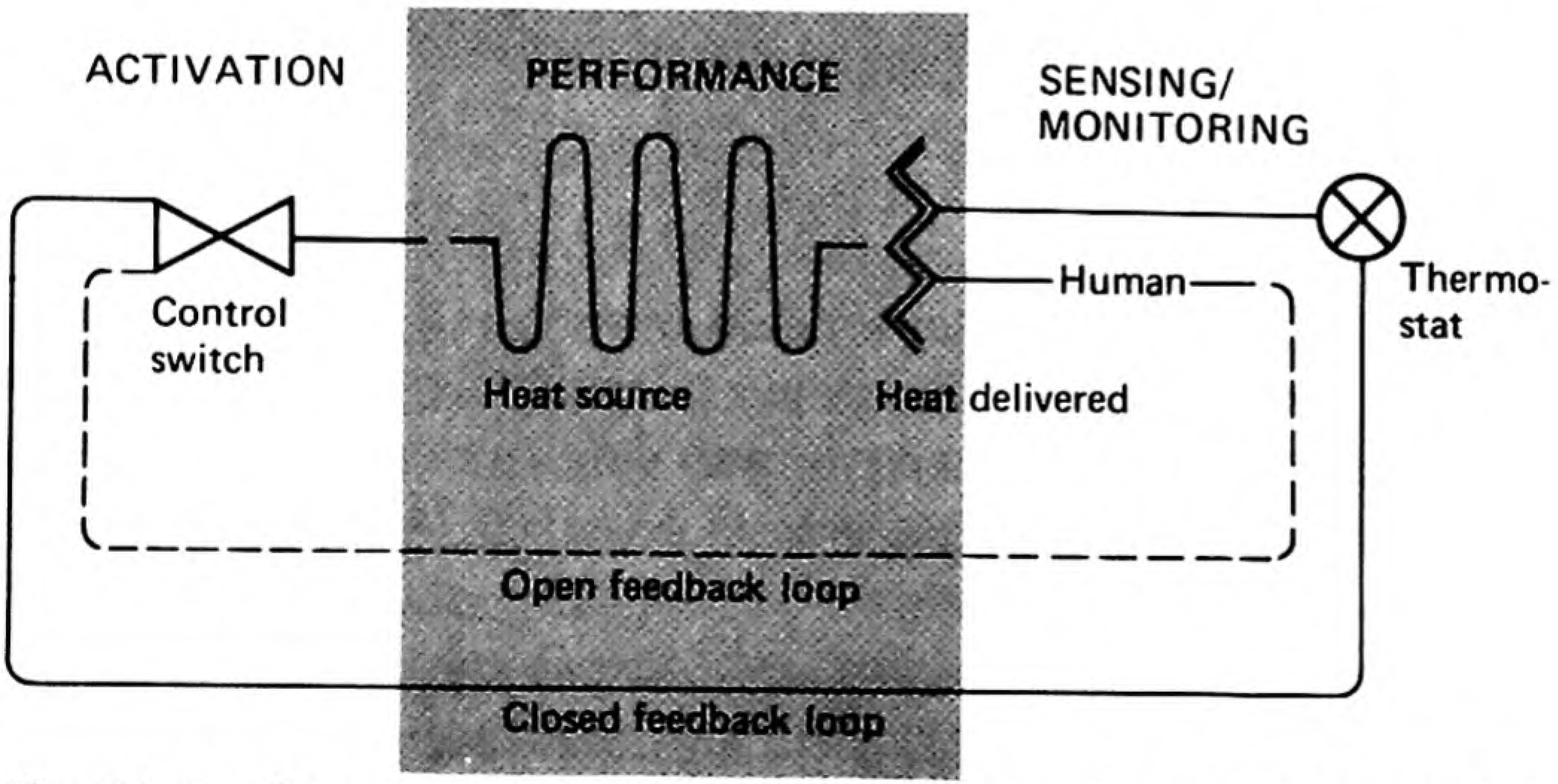


*Fig. 11-2. Open and closed feedback control system for heating. Both systems sense the output (amount of heat delivered) and compare it to a standard (comfortable room temperature). Performance (heat source) responds to a control switch that is activated by a human or a mechanical device (thermostat).*

loop. They measure output, compare the results to expectations, and initiate corrective actions when needed. Such feedback positions may be held by a single inspector in an assembly line, an appraisal team in construction acceptance, a chain of review personnel for technical reports, a board of examiners in agency reviews, or managers in fulfilling their leadership functions. Every substantial enterprise has to have a web of feedback loops to check its state of health continually.

In the following sections we will consider several tools and procedures that are widely used to regulate operations and processes. All of them contribute to feedback control in different situations. There are, of course, many variations, but they are all designed to assist control through formalized methods to compare what is happening to what is supposed to happen.

## PROCESS CONTROL

Managers see a process as a number of related activities or operations. Some processes involve only a few elements. Others encompass a broad collection of components. In effect, a major process is an integrated system of smaller processes. Middle-level managers should seek control over the processes for which they are responsible, while understanding how their process supports a larger process and is supported by subprocesses.

It is a natural tendency to devote primary attention to a local process, leaving the larger system for someone higher up to worry about. We are all guilty to some extent of this attitude in our daily lives, going about our business while we assume someone else will take care of the overall situation: dropping litter with the expectation that someone will eventually pick it up, exceeding posted speed limits on highways while hoping other drivers are under control, and making a half-hearted effort while expecting someone else to take up the slack. We need reminders to help us regulate the part we play in the bigger process, if the bigger process is to succeed.

### Financial Ratios

In Chapter 4 we observed some of the methods employed to manage money. A sound financial position is the bedrock upon which successful enterprises are built. Accounting is the analysis tool that measures the financial condition. Figures from the financial statements are the feedback data managers rely on to regulate performance and to guide planning.

Certain figures from financial statements have proved especially good indicators of performance. Two figures are often compared as a ratio. When a ratio is above or below a zone that indicates good performance, it is a signal to the manager that something should be done. The manager in this open feedback loop then adjusts the process in the direction indicated by the misbehaving ratio.

Several commonly used ratios are mentioned in the following paragraphs. They are not explained in detail because they are intended as examples to illustrate just a few of the feedback control practices relying on accounting records.

A *working capital ratio* is an indication of a firm's *liquidity*—its ability to meet current financial obligations as they become due.

$$\text{Working capital ratio} = \frac{\text{current assets}}{\text{current liabilities}}$$

The safety zone for the ratio depends on the type of enterprise it represents. Some trade associations publish industry averages for working capital ratios that can be used for comparison. When inventories and prepaid expenses are subtracted from the current assets, the working capital ratio is converted to the *acid test ratio*. The acid test is a more rigorous evaluation of liquidity.

The *accounts receivable turnover* is a ratio that indicates how quickly accounts receivable are converted to cash.

$$\text{Accounts receivable turnover} = \frac{\text{credit sales}}{\text{average level of accounts receivable}}$$

A low ratio suggests that a firm has loose credit standards or is weak in collecting outstanding debts.

*Inventory turnover* is a ratio used to evaluate the passage of goods through a firm's operations.

$$\text{Inventory turnover} = \frac{\text{cost of goods sold}}{\text{average inventory level}}$$

An excessively high ratio suggests the possibility of losing sales from goods being unavailable if the inventory supply happens to get interrupted. When the ratio gets very small, it indicates that too much capital may be locked into inventory reserves, thus limiting the firm's ability to invest in more profitable alternatives.

We can gain a rough indication of productivity by analyzing several ratios. There is still considerable speculation as to the most appropriate measure of productivity. One method is to calculate the *value added* to output per person on the payroll. A formula for this computation is

$$\text{Value added per person} = \frac{(1) + (2) + (3) + (4) + (5) + (6)}{\text{average number of employees during the period under consideration}}$$

where (1) = net profit
(2) = salaries and wages paid to employees
(3) = financial expense such as interest paid on loans, cost of discounting notes receivable, interest on bonds, etc.
(4) = rentals
(5) = taxes and public charges
(6) = depreciation expenses

The expression of value added can be used in several ratios to investigate productivity:

$$\text{Value added to gross sales ratio} = \frac{\text{value added}}{\text{gross sales}}$$

$$\text{Equipment investment ratio} = \frac{\text{value added}}{\text{book value of manufacturing assets}}$$

Other ratios that contribute to the analysis of productivity include

$$\text{Equipment turnover ratio} = \frac{\text{gross sales}}{\text{book value of manufacturing assets}}$$

$$\text{Equipment intensification ratio} = \frac{\text{book value of manufacturing assets}}{\text{number of workers}}$$

$$\text{Profit per worker} = \frac{\text{net profit}}{\text{number of workers}}$$

Managers can derive more information from ratios by observing their current value with respect to past performance. By plotting ratios from successive accounting periods, trends may become apparent. Erratic movement from an established trend is important feedback information. A ratio that moves sharply

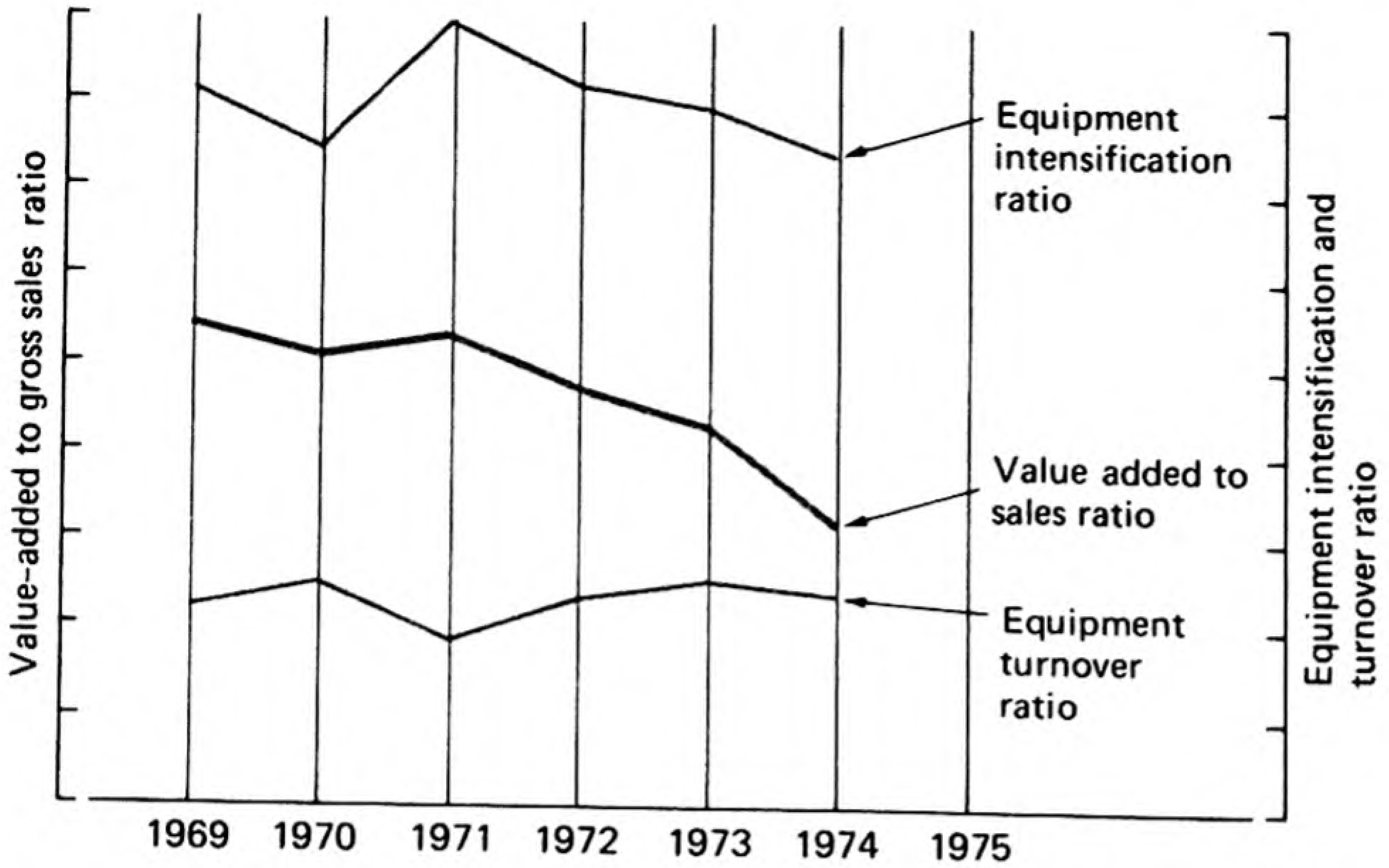


*Fig. 11-3. Rough productivity analysis by ratio trend patterns. By studying the pattern of successive ratios, a manager learns how added investments in equipment have added to sales and whether worker productivity is being maintained in relation to changes in business activity. The pattern in the chart suggests that the firm may be overstaffed.*

in an undesirable direction is an obvious cause for alarm. A major shift in a favorable direction also deserves attention to determine what factors contributed to the improvement. A typical chart for related productivity ratios is shown in Figure 11-3.

### Personnel Appraisal

Appraising the performance of people is a much more delicate affair than the evaluation of financial ratios. The ratios are sterile indicators of group achievements while appraisals of people usually involve value judgments in performance areas that are difficult to rate numerically. Appraisal procedures are designed to remove as much personal and personality bias as possible from the "sensing" phase of feedback, but the "activating" phase necessarily recognizes differences among individuals. What turns one person "on," turns another one "off." Thus the manager in the open feedback loop of human-performance appraisal must use his leadership talents to sense what behavior is needed and to detect what must be done to activate the desired response.

Many manual jobs can be precisely defined as we observed in Chapter 7. Time and motion studies spell out the content of the work to be done. Both the worker and the supervisor know how much productivity is expected. Deviations from expectations are evident from the number of items produced, rejects or number of errors, damage to equipment, etc. Correcting the deviations is not as easy as detecting them. Occasionally just calling attention to the irregularity will correct it. More often it is necessary to search for an underlying cause of the deficiency. Perhaps training was inadequate or the job itself is not compatible with the job holder. Then the manager must decide whether the work or the worker should be changed to regain control over the process.

Jobs that involve administrative duties can seldom be defined completely with work standards. For instance, a receptionist may spend part of the time typing routine reports for which standard descriptions are applicable, but the main duty of meeting and directing people resists a detailed description. It is insufficient to say that giving the right directions to callers fulfills the responsibilities because the way those directions are given and the impression created are also very important.

Feedback information about the performance of support personnel, such as receptionists, is frequently obtained by follow-up reviews on previously established performance goals. This approach is the *management by objectives* program described in Chapter 9. Part of the goal agreement between an employee and the supervisor includes a way to measure goal achievement. A number of times a year the employee and supervisor meet to discuss accomplishments and to reset goals, with better results, we would hope, than those pictured in Figure 11-4. In the language of feedback control, the meeting is the sensing mechanism, the goal achievement measurement is the monitor, and the session to set new goals is the activation phase.

A novel method of appraising group performance uses the technique of work sampling described in Chapter 7. The method was devised by the Northrop Corporation and named *performance and cost evaluation* (PACE).[1] The concepts of PACE are still interesting even though the method has never been fully accepted by industry.

PACE is designed to measure the effectiveness of a team working on an assigned project. Measurements include four key factors: (1) number of persons assigned to the project, (2) number idle, (3) number absent from the project area, and (4) the group-effort rating. These factors are combined into a formula to provide a

$$\text{PACE index} = \frac{(1) - (2) - (3)}{(1)} \times (4) \times 100\%$$

where the group-effort rating (4) has a basepoint of 1.0 for a normal tempo of work.

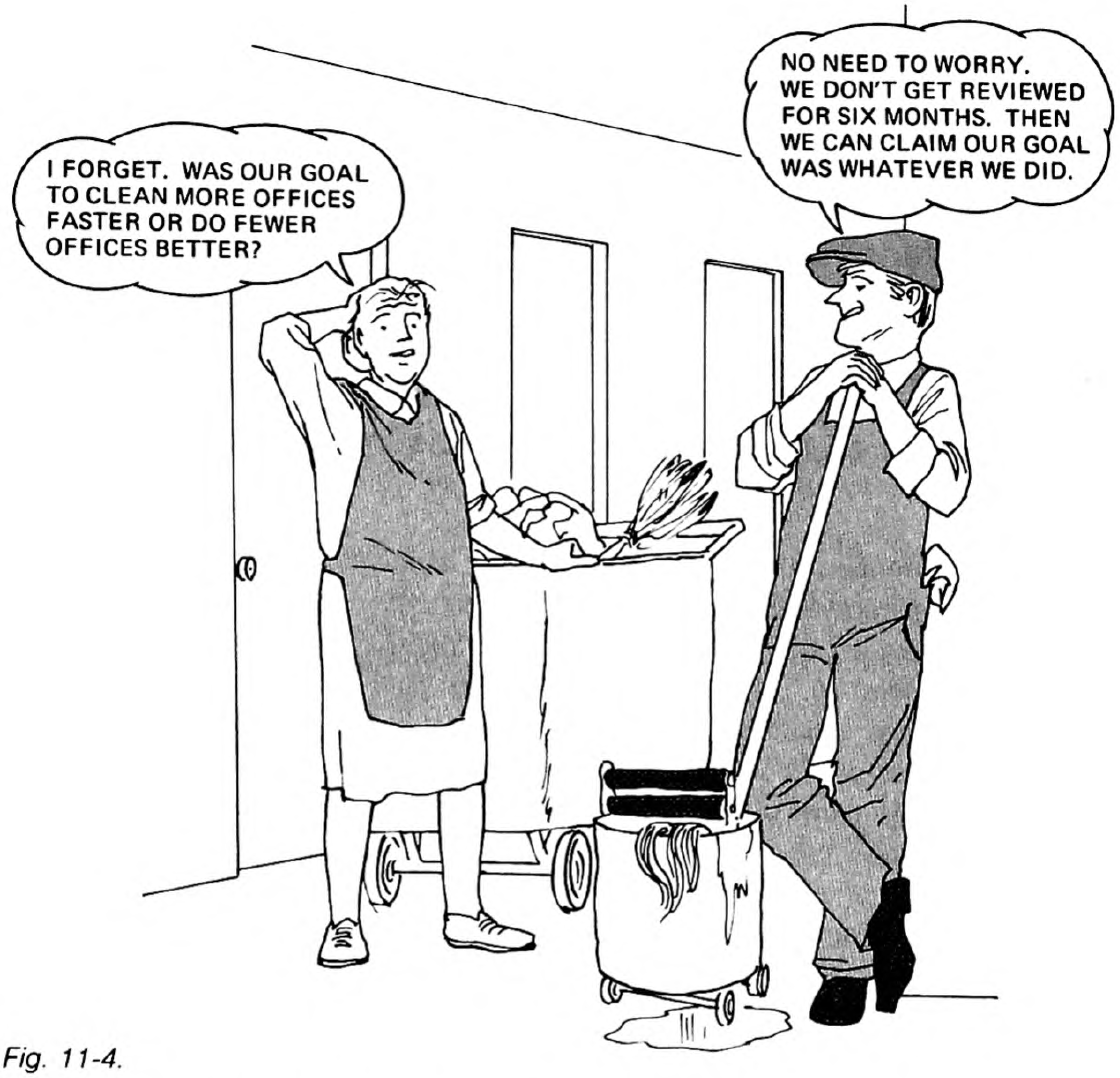

I FORGET. WAS OUR GOAL TO CLEAN MORE OFFICES FASTER OR DO FEWER OFFICES BETTER?
NO NEED TO WORRY. WE DON'T GET REVIEWED FOR SIX MONTHS. THEN WE CAN CLAIM OUR GOAL WAS WHATEVER WE DID.

*Fig. 11-4.*

The values for the four factors are obtained by having trained observers make head counts in the work area at random intervals. Guidelines are established to define each state, such as gossiping versus "talking shop" and to rate the effectiveness of group activities. As in most personnel appraisal methods, PACE depends on subjective evaluations by the observers, but it provides a systematic framework for the evaluations. A chart of the PACE index and related factors allows managers to appraise the trend of the observations, as shown in Figure 11-5.

### Production Charts

The goal of production control is to meet scheduled delivery times. All forms of production are regulated to some degree by time limitations: deadlines for submitting a newspaper story, curtain time for a play, due date for

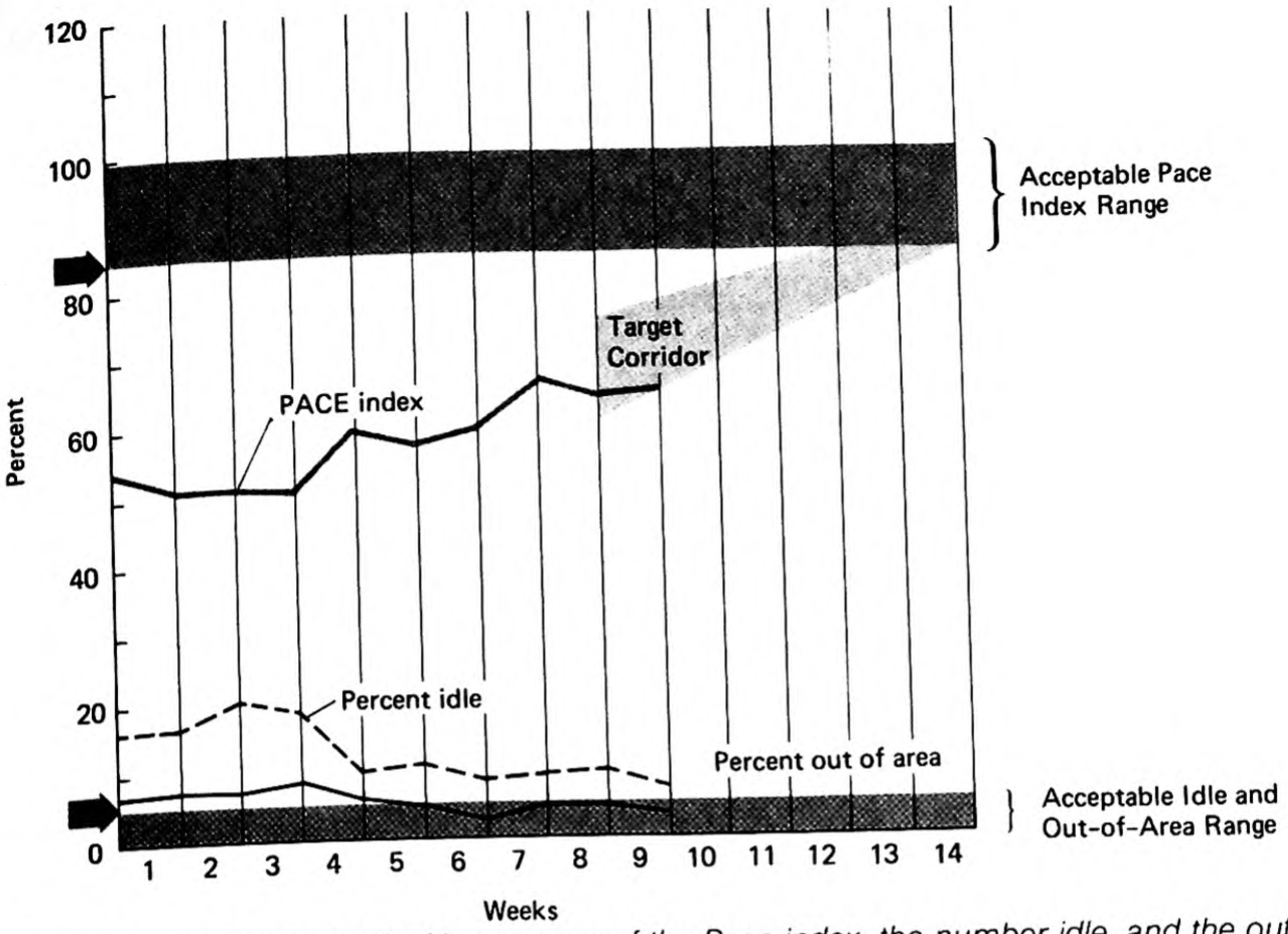


*Fig. 11-5. PACE chart. Weekly averages of the Pace index, the number idle, and the out-of-area percentages are plotted to determine the trend of group performance. The upper shaded area of the chart shows the acceptable range for a mature PACE index (85 to 100%) and the target corridor defines acceptable progress for initial PACE index values. The lower 5% band represents the acceptable range for the idle time and out-of-area percentages. Whenever a weekly reading falls outside the shaded zones in an established PACE program, management is expected to investigate to find the cause.*

a report, or delivery promises for manufactured products. Each of these situations is guided by a schedule, formal or informal. The thrust of production control is to call attention to any slippage in the schedule while there is still time to take corrective action.

One of the oldest production control devices is the Gantt chart. We have already observed its form in Figure 1-2 of Chapter 1 and Figure 6-6 of Chapter 6. The bracket bars on the chart represent planned operations and provide the target or expected level of performance for feedback control. A supervisor periodically checks the progress of operations and marks the completed portion on the bars, usually with heavy horizontal lines between the brackets. When actual performance falls far enough behind planned performance to threaten the desired delivery date, it is a signal to take corrective measures.

The Gantt chart was a prototype for many modern variations. The devices range from mechanical boards to computer printouts, and all of them serve essentially the same function of systematizing the information flow needed to control production.

Many commercial models of mechanical control are available. One type uses strips of paper fitted into slots on a time-scaled board to represent the loading of different facilities; colored signals are inserted to show accomplishments and planned overloads. Another device is based on a perforated board into which pegs can be inserted; strings between the pegs symbolize work loads. Magnetic boards use labeled metal strips to represent assigned work. An "in-and-out" board has pockets corresponding to days of a month into which job cards are placed; one section of the board shows when jobs are "due in" to a facility, and another section indicates when the same jobs are "due out." Job cards are also used in computerized production control. Formats for the computer printouts vary according to the purpose of the program, but they usually reveal all the information associated with a hand-drawn Gantt chart plus accounting data about ongoing work.

Which type of visual display to use depends on the type of feedback system in operation. A closed system requires a computer connected to sensing devices in the production area which continually monitor performance. This arrangement is commonly called "on-line, real-time process control." Charts are useful in an open system to assist supervisors in keeping track of work progress and in communicating with workers. But the charts do not automatically reveal what has to be done to correct production delays. A chart can alert the supervisor to malfunctions without telling the cause. Thus the activating mechanism in the feedback loop depends on the choice of corrective actions available to the supervisor. Selection of the most appropriate action is another example of the art of management aided by graphic art.

## PROJECT CONTROL

Constructing a building, producing a unique product, conducting a special sales campaign, and building a prototype machine are examples of a project. In a project there are distinct starting and finishing points for an undertaking with specific, narrow goals. Projects are usually part of a larger total process. For example, the continuing process of a construction firm is to provide the services required to build things; then individual projects conducted by the firm are single operations which are not likely to be repeated again in the same form.

The reason for distinguishing between process and project control is to explore management techniques developed especially for limited undertakings. Many control methods, such as Gantt charts for process control, are also appropriate for project control. In the following sections we will consider management controls associated primarily with once-only projects.

### PERT/COST

With the development of network-based scheduling (see Chapter 6) came network-based cost control for projects. The coupling is a natural, though it was not immediately accepted as workable. In the early 1960s, after the value of CPM and PERT had been proved for project scheduling, some government agencies started requiring network cost controls. Because these controls stipulated a different type of accounting system than was customarily used, firms were reluctant to cooperate. After industry became better acquainted with the system, often referred to as PERT/COST, many project-oriented firms adopted the procedures on their own.

Conventional accounting methods associate costs with organizational units such as divisions, departments, or sections. In PERT/COST the accounting units are "work packages" composed of individual activities or groups of related activities found on the network schedule for a project. The rationale for this approach is that managers responsible for completion of segments of a project should also bear responsibility for their costs.

The basic advantage of cost accounting by work packages is that cost overruns are easier to detect and corrective actions are more readily initiated. If traditional accounting is used, higher than expected expenditures in a department might be caused by any number of activities in which that department is engaged. When costs are measured and reported by activities, the source of the overrun is immediately apparent.

Several disadvantages of PERT/COST have limited its wider acceptance. Besides the obvious physical problem of converting an existing accounting system to a new form, there are also theoretical questions about how to allocate overhead charges. Should all activities be charged for legal costs incurred on behalf of the entire project? If so, how should such costs be prorated? Assuming overhead expenses are spread among activities, a user may find himself inundated with details, perhaps more than he can handle and certainly more than he wishes to pass along to his customers or contracting agencies.

Once the difficulties of implementing PERT/COST have been overcome, the amount and speed of information feedback it fosters can lead to better project control. An example of the graphic reports which result from a PERT/COST

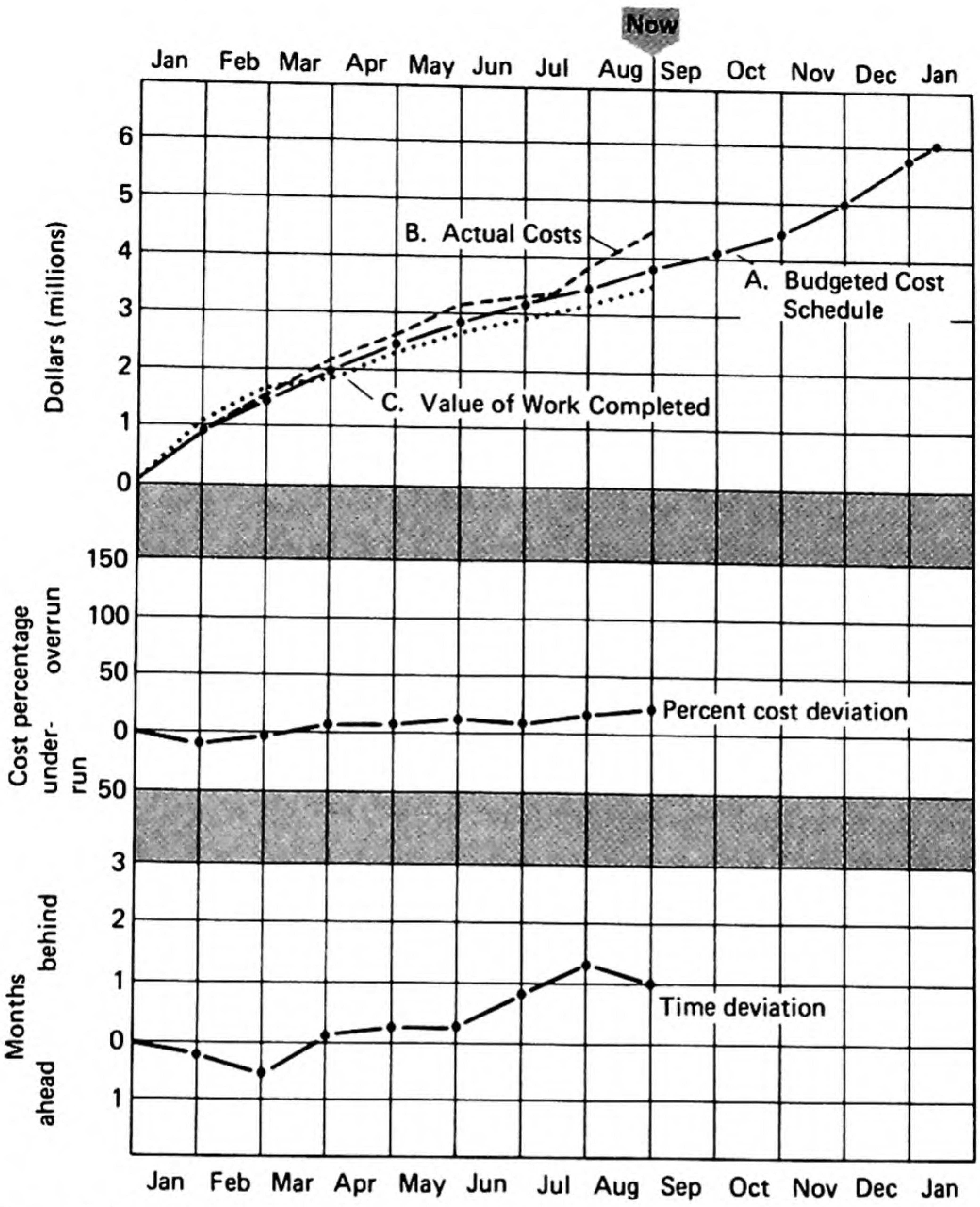


*Fig. 11-6. Comparison of actual project costs and work completed with the budgeted schedule. A cost budget is prepared by estimating the expenses for all activities drawn in a project network. Cumulative costs for the budget are determined by adding the cost of individual activities scheduled to be worked on in each time period. Then inspectors estimate the actual cost and amount of work done during each period as the project progresses.*

application is shown in Figure 11-6. The solid line (line A) in the top section of the display shows the planned cost for the project. The timetable of expense is obtained by adding cumulatively the cost for all activities scheduled to be worked on during each weekly or monthly period. The resulting line is the budgeted cost schedule against which actual performance is compared.

The other two lines in the top section are a record of actual performance. The dashed line (line B) shows the amount of money so far expended. The dotted line (line C) indicates the value of work thus far completed as measured on the basis of the original cost estimates. In the example given, there is an overrun in costs. Note that the actual cost line (B) is running above the work value line (C).

An indication of the seriousness of an overrun is given by the curves in the lower portion of the display. The cost deviation line is based on the formula

$$\text{\% Cost deviation} = \frac{(\text{actual cost}) - (\text{value of work completed})}{\text{value of work completed}} \times 100$$

where a negative value indicates an underrun. The graph at the bottom displays current completion progress compared with progress anticipated in the original budget. The cost values of two curves (line A and line C) are converted to a time value by measuring the *horizontal* distance between curve C and the point with the same dollar value on curve A. When curve C is below A, the project is behind schedule.

The manager of the project displayed in Figure 11-6 faces a serious situation. His current cost overrun is about 29 percent and his work progress is about a month behind expectation. In addition, neither excesses in cost or time appear to be diminishing as the project nears completion. Both the magnitude of deviations and their trends guide the manager's decision about when to act and what options to exercise.

When cost overruns get excessive and delays approach the danger point, a manager seeks the specific sources of his overages. Cost curves are developed for major subdivisions of the project such as progress on different components, testing facilities, fabrication output, site preparations, or basic operations. When the troublesome subdivisions are detected, more details are sought from reports on appropriate work packages and related activities. This information should reveal whether the overages are the result of general problems or are traceable to isolated instances of poor performance.

After the sources responsible for the overages are known, the project manager has still to decide whether to exert his resources to catch up with the original time and cost schedule or to negotiate a new schedule. Both options are loaded with pitfalls. A catch-up program can be treacherously expensive because resources tend to be expended inefficiently due to crowded conditions, makeshift arrangements, and hurried planning. Often it is impossible to get the needed resources for a crash program even if that seems the desirable option. Then the project must be extended. The extra time may afford an opportunity to regain control over costs in order to approach the original total project budget. But the time extension could have hidden long-run penalties from loss of reputation and from the ire of customers who had counted on the promised delivery schedule. Thus neither a hasty catch-up race nor a contrived stretch-out is a very satisfying solution, but either one is better than being unaware of the project difficulties until the full failure becomes evident at the end.

### Line of Balance

The *line of balance* technique (LOB) is an excellent example of the place graphic tools can play in feedback control. LOB is simple to use and easy to understand. It provides graphic representations of the project objective, schedule of expected accomplishments, current progress on the schedule, and comparisons of planned to actual accomplishments. Since its introduction about 30 years ago, the technique has been used successfully for programs ranging from small to huge, with applications done manually or by computers. In addition, the visual attributes of LOB make it especially valuable for communication between suppliers, contractors, and contracting agencies, as well as for internal exchanges.

The essence of LOB is demonstrated by

1. A *program plan* that describes the activities required to produce one unit of output
2. An *objective chart* that records actual and scheduled deliveries for the project
3. A *progress chart* that shows the state of each activity at a given time
4. A *line of balance* that relates the state of each activity to what the state should be if the project is exactly on schedule

The way these displays are used in project control is easy to follow with an example. The following sample application is not demanding enough for a real test of LOB, but it serves nicely to illustrate the key features.

A small novelty shop makes holiday displays and wholesales them to chain stores across the country. The current project is Christmas wreaths. The wreaths cannot be fabricated too far in advance of the Christmas season because they wilt or fall apart. Twenty wreaths of slightly different designs are packaged to form one output unit. A program plan to produce one unit of wreaths is shown in Figure 11-7.

The program plan is a time-scaled network of events that must be done to produce one unit of output. The time scale runs from right to left indicating how

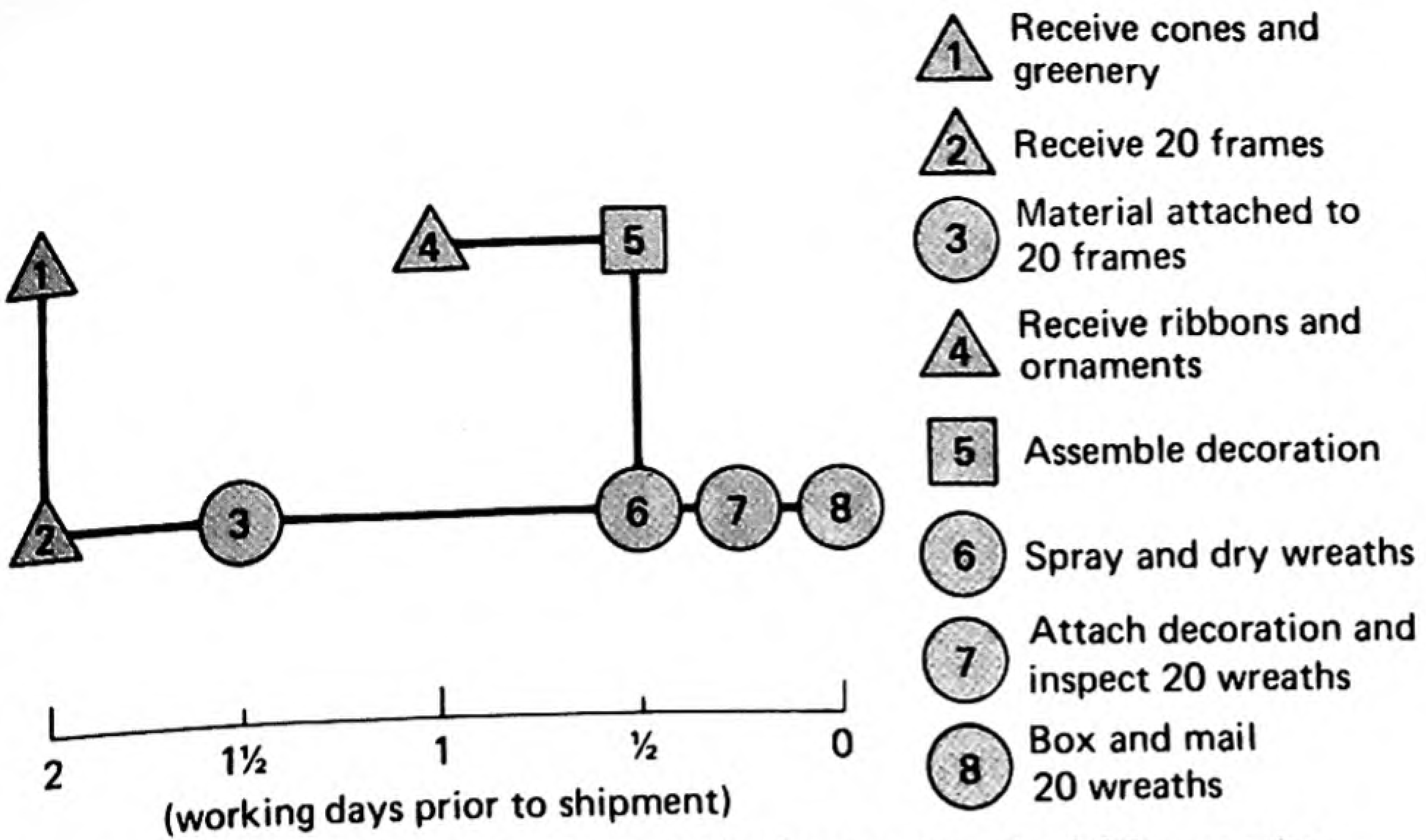

1
2
3
4
5
6
7
8
1 Receive cones and greenery
2 Receive 20 frames
3 Material attached to 20 frames
4 Receive ribbons and ornaments
5 Assemble decoration
6 Spray and dry wreaths
7 Attach decoration and inspect 20 wreaths
8 Box and mail 20 wreaths
2
1½
1
½
0
(working days prior to shipment)

*Fig. 11-7. Program plan for producing one unit of 20 wreaths.*

soon each event must be finished before the unit is completed. Events are represented by symbols and descriptions: triangles represent purchases, squares denote subassemblies made internally or acquired by contract, and circles show the main operations of the producer. From the program plan it is apparent that it takes the novelty shop two days to satisfy an order for 20 wreaths. Total output can be made much higher, of course, by working on several units at the same time.

A record of promised deliveries is shown on the objective chart as pictured in Figure 11-8. As production gets underway on the order, a record of the deliveries is maintained on the same chart. In our example the promised delivery line is linear, but in many production situations the line curves upward to reflect a condition where project personnel produce later units at a faster rate because of their increasing experience.

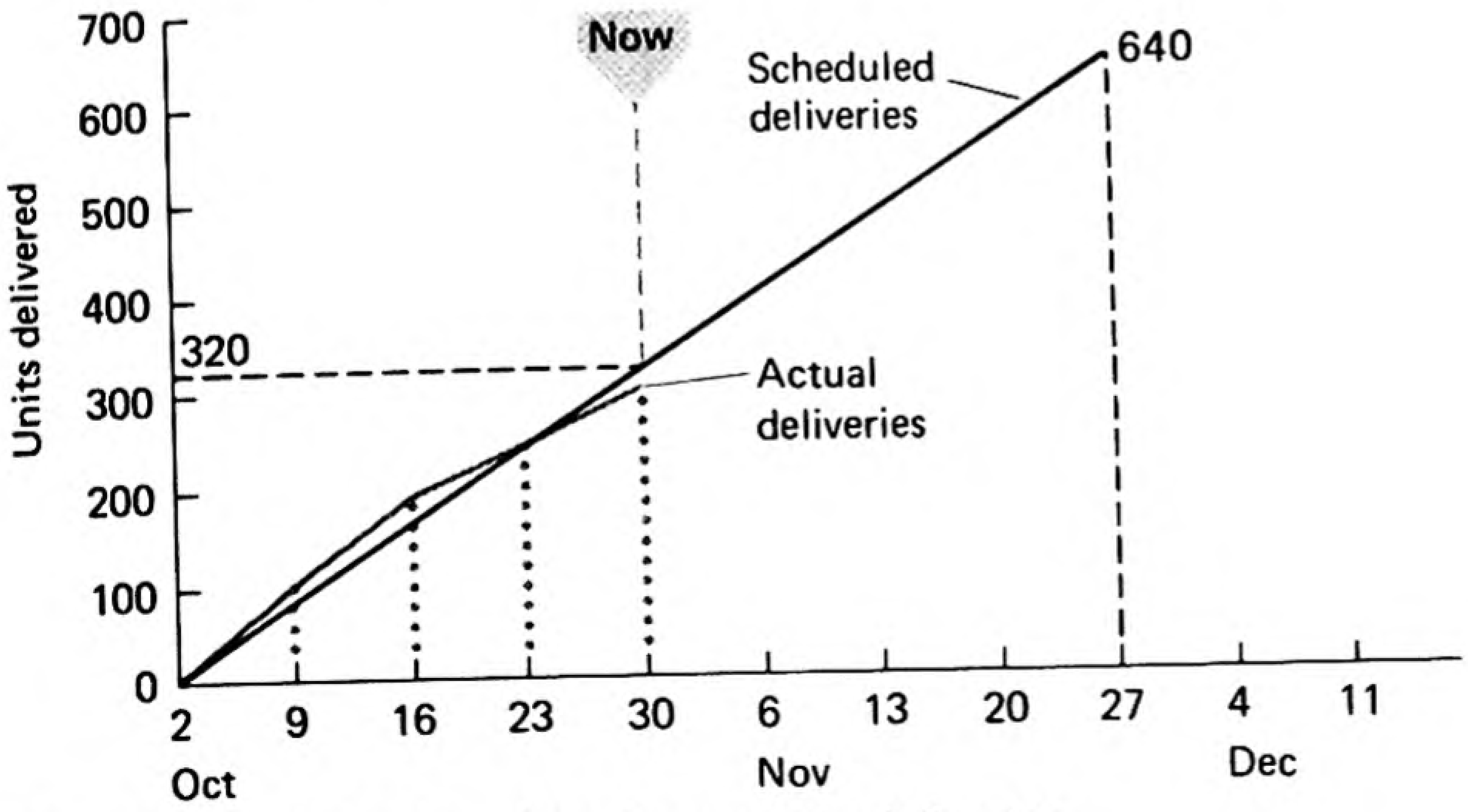


*Fig. 11-8. Objective chart for wreath deliveries.*

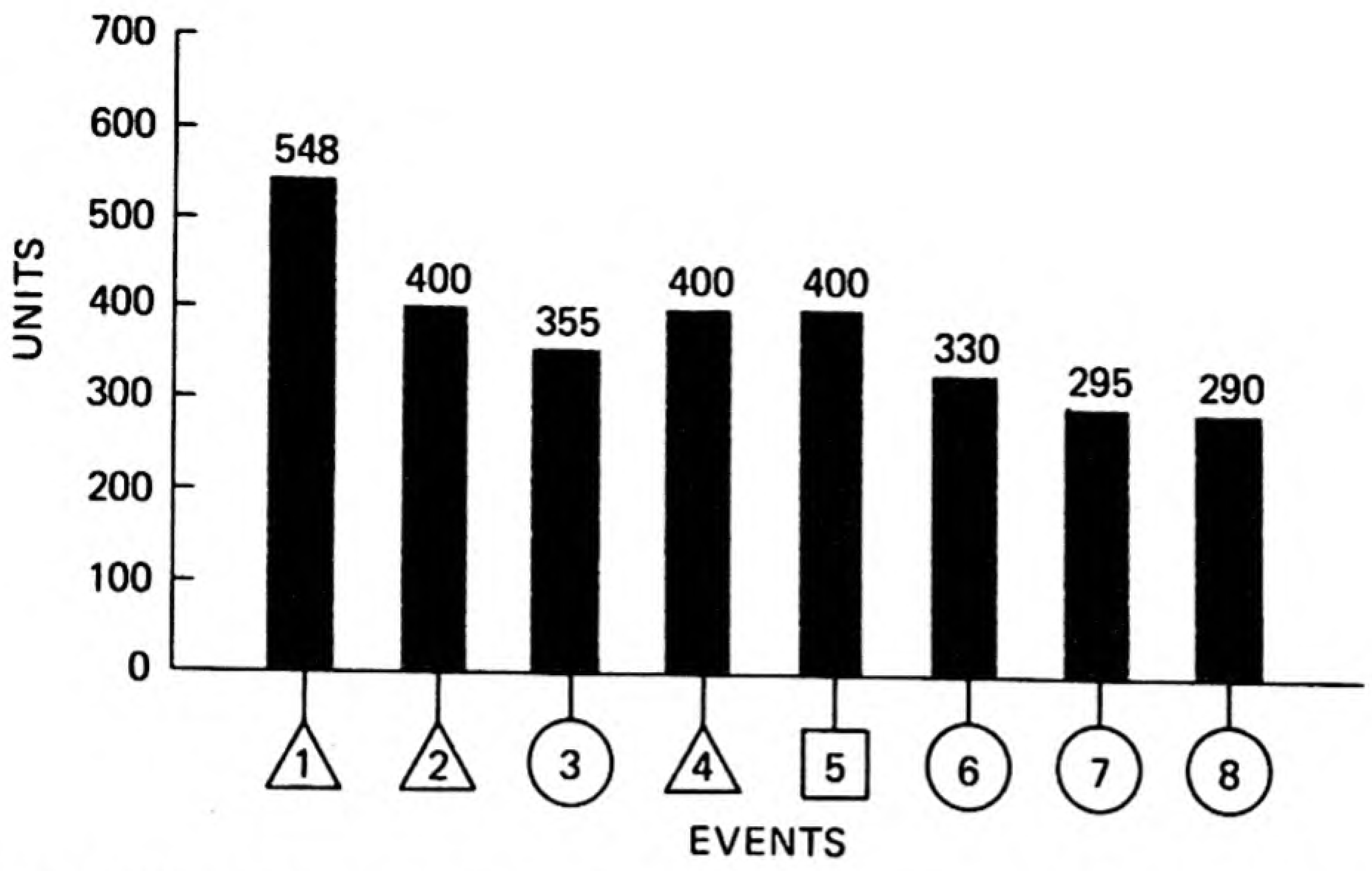


*Fig. 11-9. Progress chart of the status of events on Oct. 30. The number of units represented by each bar is posted for convenient reference.*

The principal source of feedback about the status of the project is located in the progress chart as displayed in Figure 11-9. The current status of each event is represented by a bar. The height of the bar shows the physical count of how many units have passed the given event. For example, in Figure 11-9 which gives the project status at the end of the fourth week, October 30th, the bar for event 1 shows that enough cones and greenery have been received to fabricate 548 units. Similarly, the bar at event 8 signifies that 290 units have been shipped. This amount is confirmed by the end point of the "actual deliveries" line in Figure 11-8. At the end of each reporting period the height of the bars is increased to show the accomplishments since the last period.

The final feature of LOB is a line drawn on the progress chart to show what the level of each event bar would be if the project were exactly on schedule. This line is appropriately known as the *line of balance.* It is usually constructed by scaling information from the objective chart and transferring it to the progress chart. To aid the transfer, the two charts are typically drawn side by side. This formation is shown in Figure 11-10.

The different levels of the line of balance can be calculated as easily as they are scaled off the objective chart. Computerized versions naturally use the calculation procedure. In our example, it is evident from the objective chart that 80 units are expected to be delivered each week. Assuming the novelty shop has a five-day week, 16 units must be produced each day. Since October 30th marks the end of the fourth week of the project, 320 units should have been completed by time "now" (20 days × 16 units per day = 320 units). At this same date enough units should have passed event 6 to meet delivery

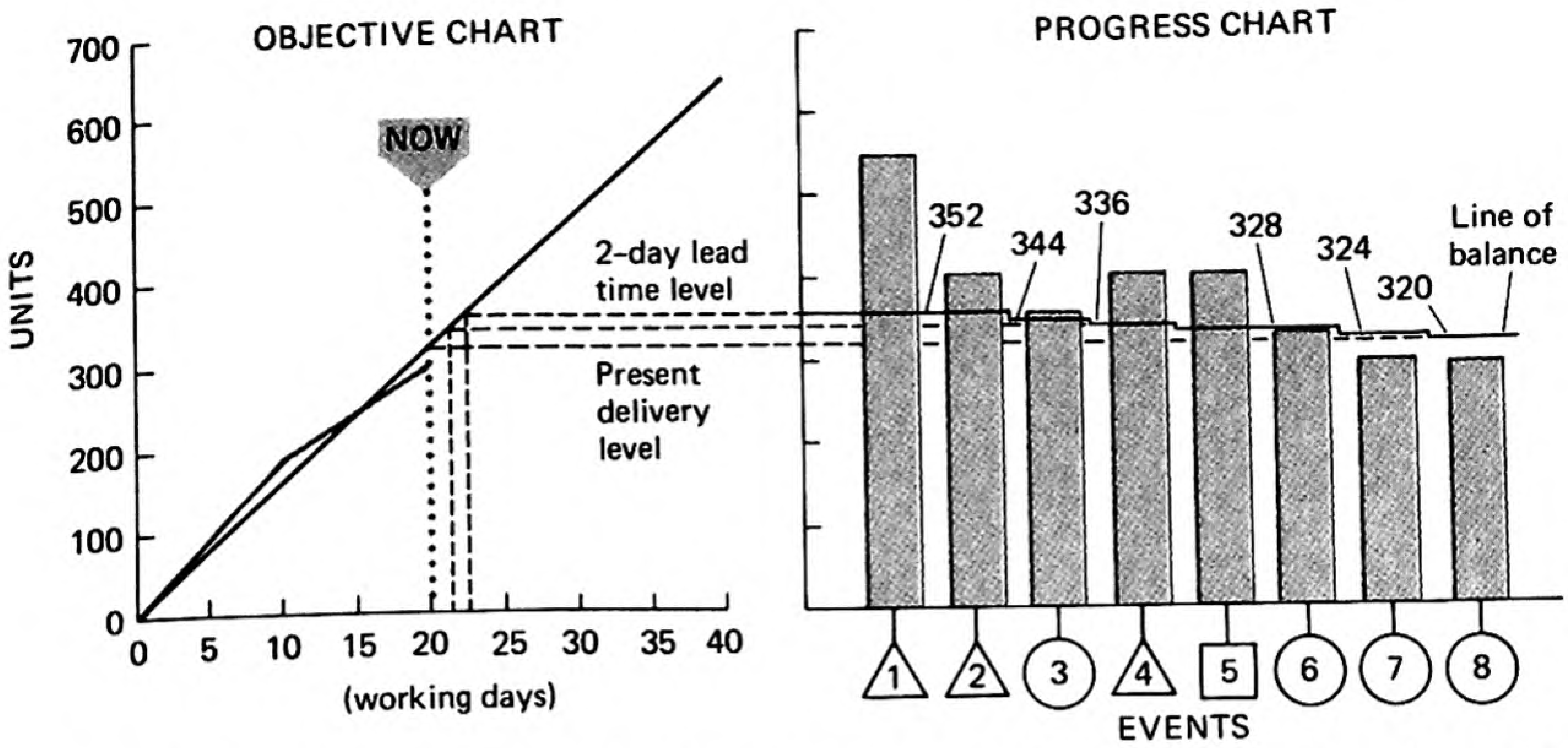


*Fig. 11-10. A line of balance struck from the objective chart to show on-schedule event levels on the progress chart. Numbers of units indicated by different levels of the line of balance are listed to aid comparisons. Lead times are shown in Figure 11-7.*

requirements another one-half day in the future; the half day is the lead time between events 6 and 8. Therefore the line of balance for event 6 is 20½ × 16 = 328 units. Similarly, 21½ × 16 = 344 units should have gone through event 3 which has a one and a half-day lead time. In effect, the line of balance is determined for each event by adding the event's lead time to the current elapsed time and then finding how many deliveries are expected by that date.

Inspection of the complete line of balance display clearly reveals which events are out of balance from their expected positions. We already knew from the objective chart that the project was behind schedule, but the favorable showing of all the events except 7 and 8 suggests that there is a good chance to catch up. Apparently the delay is in the last two stages of production, probably in event 7 because the performance at each prerequisite event sets the upper limit for the output of the following events. By slightly improving the output for the last two events and maintaining the same pace for the other events, the promised delivery schedule should be attainable.

Other problem conditions besides causes of delays can be revealed by LOB. A bar that rises high above the line of balance indicates a premature accumulation of material that might cause storage difficulties. In an application larger than our example, related events can be grouped together to give an indication of performance by particular departments or suppliers. When most of the bars for a certain function are below the expected level, a trouble area has been pinpointed. Such information is especially valuable when several subcontractors are involved in the project. Then LOB provides advice for regulating separate activities as well as for the overall project.

## MATERIAL CONTROL

Very few organizations escape the chore of material management. In manufacturing industries, material movement accounts for a major share of total costs. Wholesalers and retailers necessarily dedicate strict attention to material control. Even service agencies must be concerned with their relatively modest material needs to avoid disruptions caused by the lack of a key item. To capture the significance of material control, think of the last time you packed for a trip. You probably spent quite a bit of time deciding what to take, and still you probably forgot something. If so, you know the frustration of an inconvenience that should have been avoided. Yet you only sampled the planning, packaging, and transporting frustrations that daily occur on a far grander scale in even the smallest businesses.

### Material Ratios

In the same way financial ratios are employed to evaluate the general health of a firm, material ratios indicate the success of material management. The most common one is the *annual inventory turnover ratio*: the total value of withdrawals from inventory divided by the average inventory value. A high inventory turnover is considered desirable. This high turnover ratio means that for the same volume of production or sales, a smaller investment in raw materials or finished goods is maintained. An inventory turnover of "four" means that storage was "emptied" four times during the year. Another view of this ratio is that four times the quantity stored was used in a year.

Too high a turnover ratio increases the danger of a *stockout*—not having an inventory item that is needed or could be sold. The advantage of maintaining a minimum investment in inventory must be measured against the costs of running out of stock. Rush orders to secure needed items quickly are expensive, as are production delays caused by missing items that should have been in storage. Stockout costs for retail sales include the loss of the sale *plus* the loss of goodwill from unsatisfied customers. If enough goodwill is squandered by too many out-of-stock situations, customers will get the habit of buying from other sources. Then, you can be sure, the turnover ratio will slide from high to very low.

Two other ratios that provide interesting inventory indicators are (1) *profit to inventory ratio*—a measure of the return generated by investments in inventory, and (2) *committed inventory to total inventory ratio*—a measure of how much inventory is being stocked to meet known customer demands. These ratios offer a quick but crude evaluation of performance. More thorough evaluations are needed to judge the detailed operations of material management.

### ABC Classification System

Companies routinely stock thousands or even tens of thousands of different items in their warehouses. Half a century ago an owner-manager of a business might have had a few hundred items to watch over. He maintained control by manually kept ledgers. Now, fast-paced operations demand fast-paced material controls. Automatic production machines have to be backed by a wide range of materials available on short notice. The continuous output from mechanized production lines typically outpaces the rate at which finished products are ordered by customers. To maintain the economy of longer production runs, some finished goods are warehoused. Clerical costs to manage these inventories would be prohibitive if tight control was sought over all the materials needed to supply an industry. The solution has been to computerize record keeping and to allocate most attention to the most used inventory items.

One popular concept holds that, in any given group, a minority often governs the group's activity. Examples of this proposition are everywhere; about 20 percent of the people in this country account for 80 percent of the wealth; less than 20 percent of the items in a typical family's budget make up 80 percent of total expenses; about 10 percent of the industrial corporations in the United States employ over 75 percent of the workers; 25 percent of the world's population use over 75 percent of the energy produced each year; etc. This concept is useful to management for the regulation of many activities: just a few manufacturing operations produce most of the production rejects; a few functions cause most of the delays; a few workers are involved in most of the accidents; and *a few items in inventory account for most of the dollar volume for materials.* When this last observation is applied to inventory it is called the *ABC classification system.*

The relative importance of each inventory item can be measured by how much the total value of purchases is for that item each year. This measure is often termed the *activity level.* It shows the cash flow per period to stock an item. An item that costs $0.10 per unit, with annual purchases of one million units, has an activity level of $100,000. The manufacturer, therefore, considers this 10-cent item more important than an item which costs $200 per unit with 100 purchases annually.

It is expected that 10 to 20 percent of the total number of items in stock constitute 60 to 80 percent of the total annual value of purchases. These are classified as A items. At the other extreme, about 50 to 60 percent of the inventory items comprise only 5 to 10 percent of the value and are classified as C items. Items between the A and C ranges are B class, 20 to 40 percent of the total number accounting for about 20 percent of the total value. The actual breakdown into A, B, and C classifications for items used by an organization should be tailored to particular needs. For instance, an item with a relatively low activity level, but which could cause a severe hardship if a stockout occurred, would likely get an A classification. The more typical distribution of classifications is shown in Figure 11-11.

The ABC concept is another application of management by exception. The purpose is to put effort where it will do the most good. In material management it results in control being exercised over key items rather than dissipating it over all items. To allow more attention to A items, the C items are left almost unattended, because whatever problems arise in the C class will be relatively minor—at least in theory. Also it is believed that total expenses are lower when some extra capital is tied up in little-used items than when records are kept accurate enough to avoid stockouts. The opposite is believed true for A items. A manager will exercise the tightest possible controls for A items through close supervision of deliveries, through frequent audits of records, and through policing of ordering policies.

### Reordering Systems

In Chapter 10 we dealt with the question of the most economically sized order to place, but we did not explore the mechanics of determining when the order should be placed. In several ways the problem of *when* to order is more troublesome than deciding *how much* to order. "How much" can be decided by well-known analytical methods, though some of the methods are indeed com-

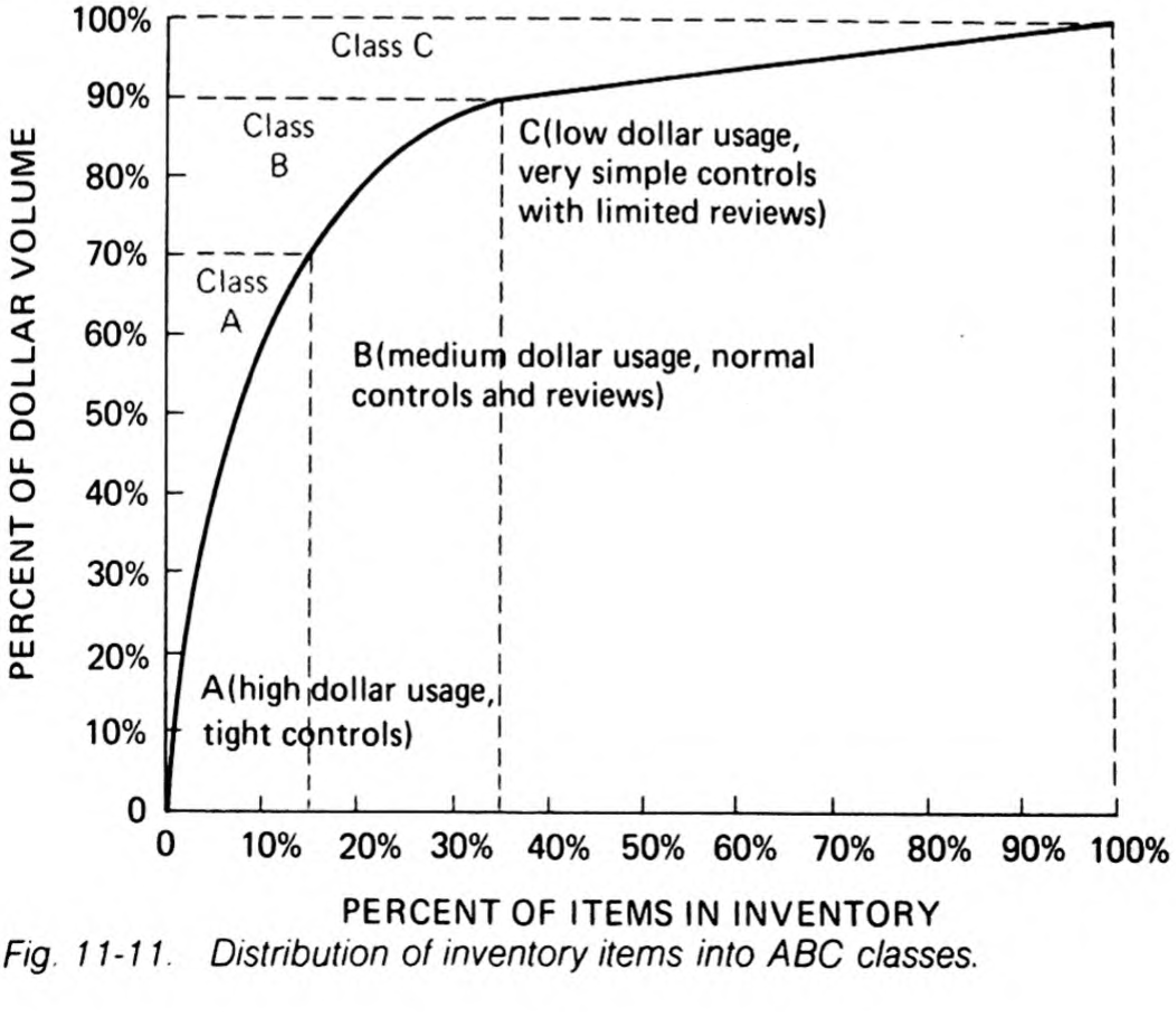


*Fig. 11-11. Distribution of inventory items into ABC classes.*

plicated. "When" involves policy decisions plus all the physical difficulties of keeping track of material flow.

All inventory systems are guided by decision rules of some kind. The rules might be as simple as "when you run out of something, order some more." But even the simplest rules have to be supported by information about supplies on hand and expected future usage. Supplies required to run a household or a small office can be ordered after a visual check of the amount on hand. The amount ordered is based on experience. A housewife checks her cupboard shelves to see what she needs. She knows about what to expect during the coming weeks for guests, special occasions, and planned activities of the family. An office clerk checks the stockroom to find the amount stored and mentally notes what should be in stock to meet the office needs in the days ahead. In both cases the reordering system consists of frequent checks on inventory levels and immediate purchases to relieve any shortages discovered.

Organizations larger than a household or office obviously have more extensive material needs and naturally have more elaborate reordering systems to satisfy those needs. The most fundamental inventory difference between large and small concerns is lead time. A housewife or an independent office manager can go to a store and directly purchase replenishments. Orders for supplies by a department in a large organization typically pass through a centralized "stores" function. If replenishments are available from the central storage facility, orders can be filled with a short lead time. If the central stores are depleted, lead time is much longer. To avoid stockouts during lead time in both the central stores and department supplies, adequate inventory records must be maintained. Knowing current inventory levels is the first step in knowing when to reorder. The next step is knowing what inventory level indicates the need to reorder.

There are three basic systems used to locate reorder points.

1. **PERPETUAL SYSTEM.** A running record of the amount in storage is kept and a *fixed order quantity* is ordered when the stock level drops to a predetermined number. The quantity to order is determined by the factors discussed for EOQ calculations in Chapter 10. In elaborate installations the stock records may be kept by a real-time computer system where withdrawals are fed to a computer programmed to issue purchase orders when the inventory drops to a certain level.

2. **PERIODIC SYSTEM.** Inventory records are checked at *fixed intervals* and when the supply is low, a quantity is ordered that brings the level up to a predetermined maximum number.

3. **PLANNED SYSTEM.** Before a project is started, the schedule of material acquisitions is matched to the work schedule. Then predetermined amounts are ordered at predetermined intervals.

The first two systems are the most common. We will explore the manual versions of both since they are easier to understand than their computerized counterparts. These manual versions predate the modern computerized ones and are still used for many smaller installations.

1. **TWO-BIN PLAN:** A version of the perpetual system. The supply of an item is physically divided into two parts, large and small, sometimes put into separate bins. The smaller part is not touched until the main stock has been consumed. When the reserve supply is broken into, a replenishment order is issued. There is supposed to be enough in the "second bin" to provide for withdrawals during the lead time before replenishments arrive. No written inventory records are needed.

2. **VISUAL REVIEW PLAN:** A version of the periodic system. The stock level is visually checked at regular intervals, such as weekly or monthly. The number on hand is usually recorded on a tag along with the date of orders placed for replenishments. At each review orders are placed, if necessary, to bring the stock level up to a predetermined maximum. The amount to order is the difference between the maximum and the stock on hand plus amounts already ordered.

Which system to use depends on the type, total, and nature of material usage. Both the perpetual and periodic systems can be adapted to follow the ABC principle. A items have proportionately larger safety stocks and more frequent deliveries than B or C items in the perpetual system. Similarly, A items are reviewed at shorter intervals than B or C items in the periodic system. For either system remember that "you can't sell what you ain't got" and "the more you carry, the harder you fall."

### Material Handling

Nearly all managers must devote some attention to the movement of materials during their careers. This attention is warranted; estimates indicate that up to 80 percent of indirect labor cost in a plant or 20 percent to 50 percent of total manufacturing cost is consumed in transporting items from one place to the next. The ratio of physical distribution costs to sales for products is about 25 percent for the food industry and 22 percent for chemical, rubber, petroleum, and primary metal industries. Costs of such magnitude are magnets for management attention.

The glaring expense of handling materials places a sharp focus on the willingness of managers to cooperate. Control of material flow is an objective that involves the activities of many departments in an organization. The activities have to be coordinated. The search for the best possible policy requires diplomacy and a willingness of managers to put the welfare of the firm above special interests of departments, a tough test of management maturity. The way in which material-handling control depends on the cooperation of managers responsible for different functions is portrayed in Figure 11-12.

The handling of materials does not increase their value other than making them more accessible. Therefore, material handling is wholly a service function. Its major objectives are to

1. Increase productivity through reduction of machine downtime from lack of materials, improve work flow in a plant, and increase efficiency in shipping and receiving.
2. Improve working conditions by reducing worker fatigue, by providing safer equipment, and by upgrading work through the introduction of automatic equipment.
3. Reduce costs by decreasing damage from handling and shipping, by using space better, by cutting pilferage, and by reducing stray shipments.

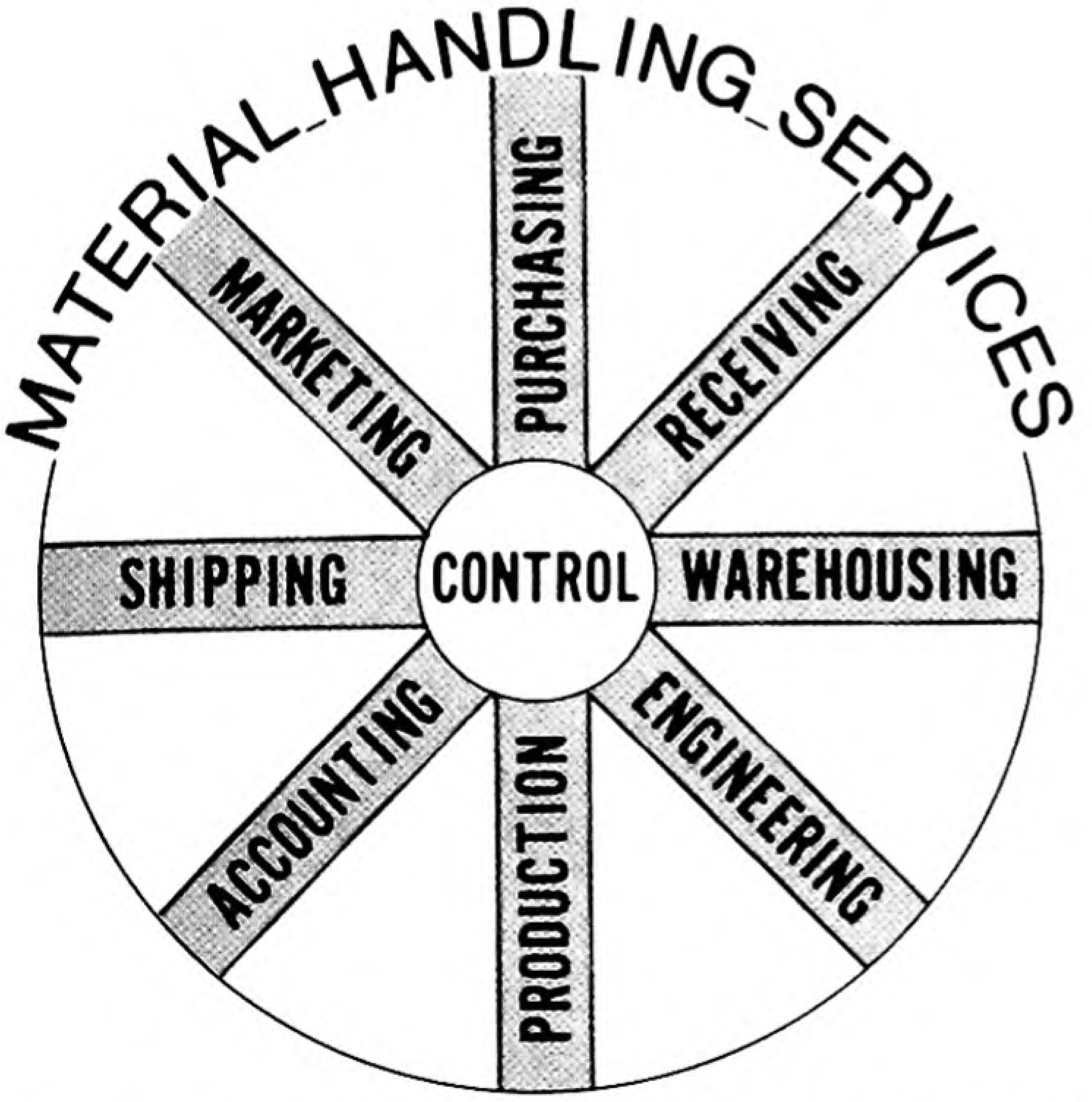


*Fig. 11-12. The material-handling wheel. The hub of material handling is control. The spokes support the rim of material-handling services which, in turn, bolster all of the functional areas.*

To managers in many nonmanufacturing organizations, material handling services begin and end with the operation of a stockroom. Supplies are purchased periodically, stored in the stockroom, and issued when needed. The simple purpose and direct service of the stockroom operation may conceal costly inefficiencies. You should ask the following questions even of small stockroom operations:

1. Are different types of supplies easy to locate and to reach?
2. Do unauthorized personnel have access to the supplies?
3. Is there enough space to store materials bought in lot sizes? Is room being wasted?
4. Are the stock records sufficiently accurate to avoid stockouts?
5. Do stored items get damaged during handling?

Such questioning may seem too severe for a simple service, but significant savings can be made even in a humble storeroom.

Material-handling improvements are especially important in manufacturing, retailing, and distribution systems. Huge quantities of materials are handled in these businesses, and handling costs represent one of the few areas where substantial savings can be attained internally. Since the cost of incoming materials is largely set by outside suppliers, how these materials are handled internally is a major factor in total profit.

Ratios are useful in evaluating material-handling effectiveness. The following ratios measure three dimensions of productivity:

1. $\text{Material-handling labor ratio} = \dfrac{\text{material-handling personnel}}{\text{total operating personnel}}$

   (The most widely accepted ratio; the proportion of an organization's labor force chargeable to material-handling needs.)

2. $\text{Space utilization efficiency ratio} = \dfrac{\text{space usefully occupied}}{\text{net usable space}}$

   (Compares the cubic feet of space that could be used to that which is actually being used.)

3. $\text{Equipment utilization ratio} = \dfrac{\text{actual output}}{\text{theoretical output}}$

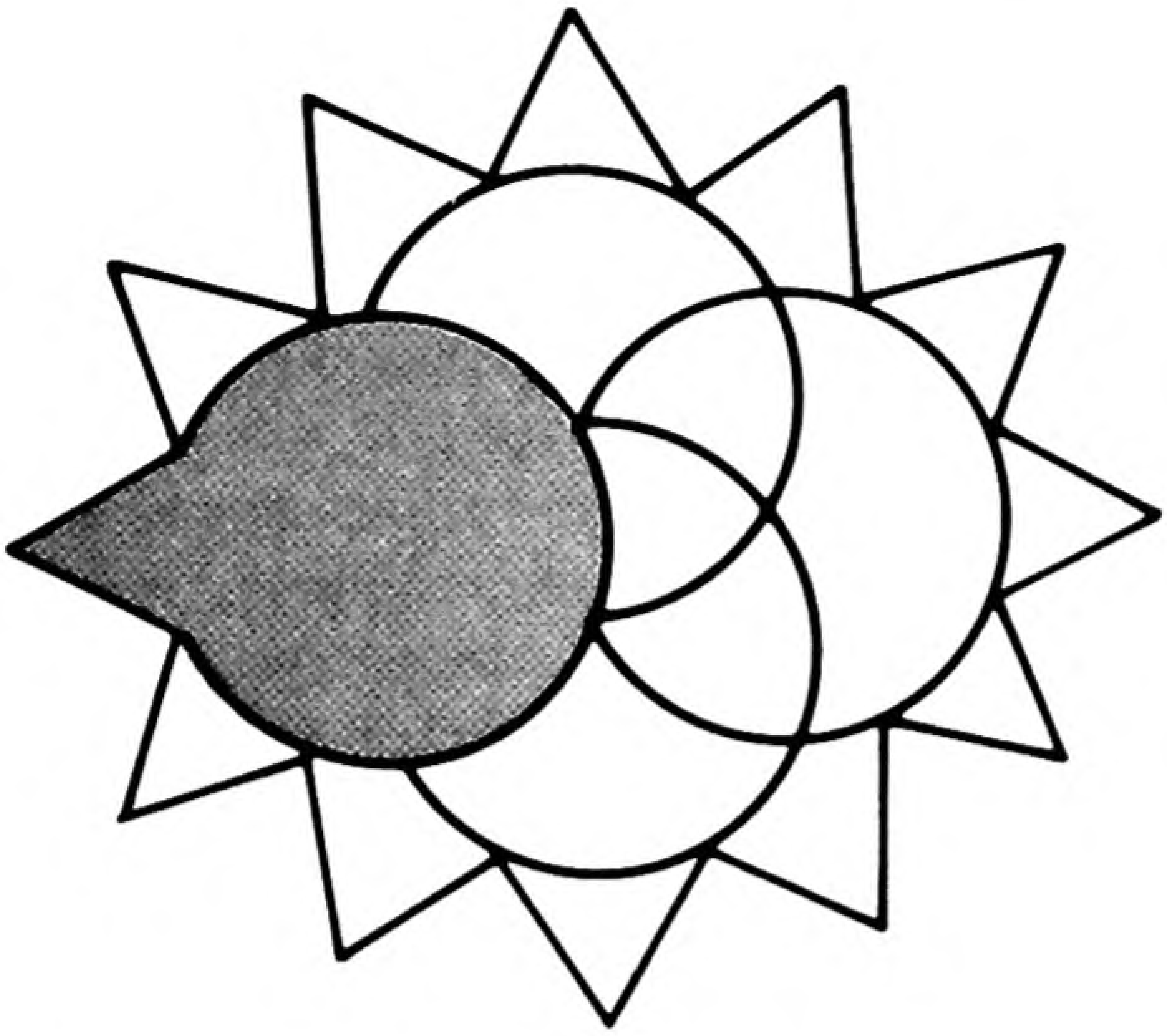
   (A measure of effectiveness that includes the effects of maintenance, scheduling, operating methods, and material handling.)

There is no magic number for the above ratios that automatically grades personnel, space, or equipment use as good or bad. The historical pattern of each ratio is the enlightening feature. Comparisons of present numbers to past numbers may indicate which areas need greater control. An area that exhibits poor performance should be investigated through detailed cost reports. Such costs are usually difficult to extract from other production costs, but the effort is worthwhile for particularly troublesome operations. *You must expose a subject before you can measure it, and you have to have measurements before you can control it.*

## REFERENCE

1. Alice L. Smith, "Northrop's PACE Program: New Cost-Cutting Tool for Management," *Dun's Review and Modern Industry,* February 1959.

# Chapter 12



# Monitoring

**KEY SUBJECTS**

*Complete process monitoring starts with consumer wants and ends with consumer satisfaction.* During the product-design phase, the value of higher technical excellence to a consumer must be weighed against the cost of producing a product with this excellence. This comparison results in product specifications. Once a process capable of the specified precision is established, output still must be checked regularly to see if the process continues to conform to the specifications. Conformance is typically checked by inspecting the output from successive phases of the process. The cost of quality is the sum of expenses arising from faulty products and the cost of preventing failures.

*Most products are subjected to some form of inspection.* Two methods of inspection are (1) *variables inspection:* measurement of a product's exact dimensions, such as length and width, and (2) *attributes inspection:* evaluation of a product's classification, such as good or bad. Inspections are conducted at points during a product's refinement where they will minimize total quality assurance costs.

*Sampling inspections rely on statistical inferences made about an entire population from inspecting only a few members of that population.* Control sampling involves occasional inspections to determine the precision of the process.

Acceptance sampling is usually associated with the inspection of incoming deliveries and with the final inspection of outgoing shipments. It is important that every unit in the population has an equal chance of being included in the sample. The number and size of product samples are influenced by the properties of the population and the degree of protection sought for both the producer and consumer.

*Control charts provide a graphic record of sampling inspections.* Statistical measures are used to determine when a process is in danger of producing nonconforming products. Inspection of variables results in $\bar{x}$ charts to detect changes in the level of the process quality and R charts to check for changes in the variability of process output. A $\bar{p}$ chart records the results of attributes sampling and suggests when the proportion of defectives produced by a process is getting out of control.

*Control charts are useful in evaluating performances in areas other than product quality.* For example, the continuing accuracy of forecasts can be checked by applying control-charting techniques. A moving-average forecast is checked on a moving-range control chart. And since the control limits on all control charts are based on the statistical properties of the system being charted, a manager can study the pattern of plotted values to gather clues about future performance. Since control charts require time and money to maintain, they should only be used when needed. When they are used, they deserve full care and attention because control charting is a powerful management tool.

*Monitoring for quality is more effective when employee participation is greater.* The task of keeping everyone involved rests largely on supervisory level managers. The *zero defect* program in this country and the *QC circle* movement in Japan are large-scale efforts to obtain more involvement. Both have had notable successes. In the future it is reasonable to expect both technological improvements in inspection devices and acceleration of interest in quality assurance.

## QUALITY ASSURANCE

Case 1: We have to decide how many errors are too many errors. In our department we issue all the registration papers for motor vehicles operated in the state. The original information is taken from handwritten application forms and entered into our computer. Errors occur in the original information and in the transfer of data from the application to the computer. We cannot afford to inspect every document, and even if we did, we could not catch all the errors. Also, some errors are minor and some are major, such as entering the wrong serial numbers. Therefore, we have to consider the cost of our errors to the public we serve and compare this cost with the budget allowed for our operations. The result is not very comforting.

Case 2: Our reputation has been built on quality. We buy fresh fruit, process it, and pack it into fancy gift boxes. We use only the finest fruit. Each box is hand packed. Such packing is expensive. We now have inspectors at the end of the line who look at every box and decide which ones meet our standards. Since our output has increased, this procedure is getting unwieldy; and we are wasting too much fruit and time in repacking the rejected boxes. We need to design a new inspection method that maintains our quality standards with less loss.

Case 3: In our lumber mill we have two big monitoring problems. One involves control over mill processes and the other involves forecasting. Process quality is relatively easy to measure since it is mostly concerned with maintaining proper sawing dimensions, but it has to give prompt corrections because we can saw an awful lot of wrong size boards when a machine adjustment slips. Forecasting control is different; what we want to know is how well our estimates of demand compare with actual demands for our lumber. It gets very expensive to store stocks of lumber cut for buyers who have decided not to buy. Although the results of process and forecasting control affect different areas, they are part of the same monitoring problem.

The cases above are just isolated instances of a near universal quest for quality. The producers in the cases view quality assurance as an organizational goal and a necessary expense. They are aware of the damages that can result from a lack of such assurance:

- Automobiles recalled for defect corrections
- Prepared foods withdrawn from the market because they are contaminated
- Devices and drugs that cannot be sold because they have not had sufficient testing or are misrepresented
- A fleet of planes grounded because a malfunctioning mechanism has to be inspected or replaced
- Huge sums paid for redemptions or for warranties when a product is faulty

Society's concern for quality is becoming more evident with the adoption of more consumer-protection laws. Courts have awarded large compensatory judgments for consumers in cases against manufacturers and distributors of defective products.

In addition to the external costs of meeting consumer expectations and regulations, there are several important internal reasons for quality control. One department in a company is often a customer of another department in the same company. The parts produced by the supplying department must meet the specifications of the receiving department. Inspection procedures can reveal defects in products early in the production process. This early detection allows the product to be reworked or scrapped before too much is invested in its completion. Checks on quality also provide information about the performance of individuals, teams, and departments. Most appraisal systems recognize the importance of quality. A measure of achievement is provided by a quality-assurance program that examines excellence of output, amount of rework needed, and amount of wasted effort as indicated by scrapped results.

In this chapter we will consider how processes can be monitored to improve quality. Because there are many types of processes and numerous ways to measure performance, quality assurance takes different forms to different people. A machine operator may view it as a level of proficiency expected of him. An inspector may associate it with statistical tables and charts. To a supervisor it means planning, explaining, and checking continuously for high quality output. Managers see it as a coordinated effort to satisfy several objectives. Examples of monitoring objectives are evident in the following descriptions of actions taken in the cases from the beginning of this section:

Case 1: Managers of the motor-vehicle registration department decided that 98 percent accuracy was a realistic goal; only two registrations per 100 could have any type of error. In the rare instances when an error was serious enough to cause financial loss to the owner of a vehicle, the department was liable. Such losses proved to be far lower than the costs required even to approach 100 percent accuracy. To ensure 98 percent accuracy, the work of each operator was randomly inspected and a chart of the results was posted at each work station. When the samples indicated that an operator was allowing too many errors, *all* that operator's printouts were inspected until the operator was consistently producing at the 98 percent accuracy level. Thus the inspection routine contributed to correct documents, to job motivation, and to employee training.

Case 2: To ensure the quality of purchased fruit, an acceptance sampling plan was designed. Each incoming shipment of fruit was sampled. The sampling plan spelled out exactly how much fruit could be below stated standards before the shipment was rejected, or penalized by requiring the supplier himself to pay for 100 percent inspection to eliminate substandard fruit.

An entirely new production procedure was established to improve the quality of the hand-packed boxes. In place of having each packer handle just one type of fruit in an assembly line, packers were made responsible for completely packing and inspecting a full box. The packer's name was put in the box and random samples of packed boxes were inspected to maintain the packing standards. Thus job enlargement and a new inspection policy were combined to yield greater quality assurance.

Case 3: Both monitoring problems in the lumber mill were eased by the use of control charts. The purpose of a control chart, as will be discussed in a later section, is to call attention to a process that is behaving suspiciously or is out of control. Machine outputs were measured and plotted on charts. These measurements were compared with maximum allowable variations determined statistically. When measured board dimensions approached or exceeded the statistical control limits, the machines were adjusted. In a similar fashion, actual demands for lumber were compared to forecasted demands. When the difference between demands varied beyond a statistically determined limit, the forecasting method was questioned. Different types of control charts were used for the two applications, but both served the purpose of detecting undesirable trends.

## COST AND VALUE OF QUALITY

Inspections are perhaps the most obvious example of costs incurred and value acquired from quality assurance programs, but a great deal more is involved. Concern for quality begins and ends with the consumer. Between the initial action to discover what products or services will sell and the final action to determine how well customers' expectations were satisfied lie all the phases of ensuring quality production.

Figure 12-1 depicts the main phases of product quality control. After consumer wants are known, a product is designed. Part of the design phase includes setting the technical specifications of the product: the tolerance allowed for different parts (a length specified as "2.000 ± 0.010 in." means it cannot be shorter than 1.990 inches or longer than 2.010 inches), quality of materials, speed of service, etc. How well the process can conform to the technical specifications depends on the capability of the process and the control that can be maintained. If a part has to be between 1.990 and 2.010 inches in length, it will obviously have to be made with equipment that can consistently produce items within the given limits. Then measuring devices capable of measuring

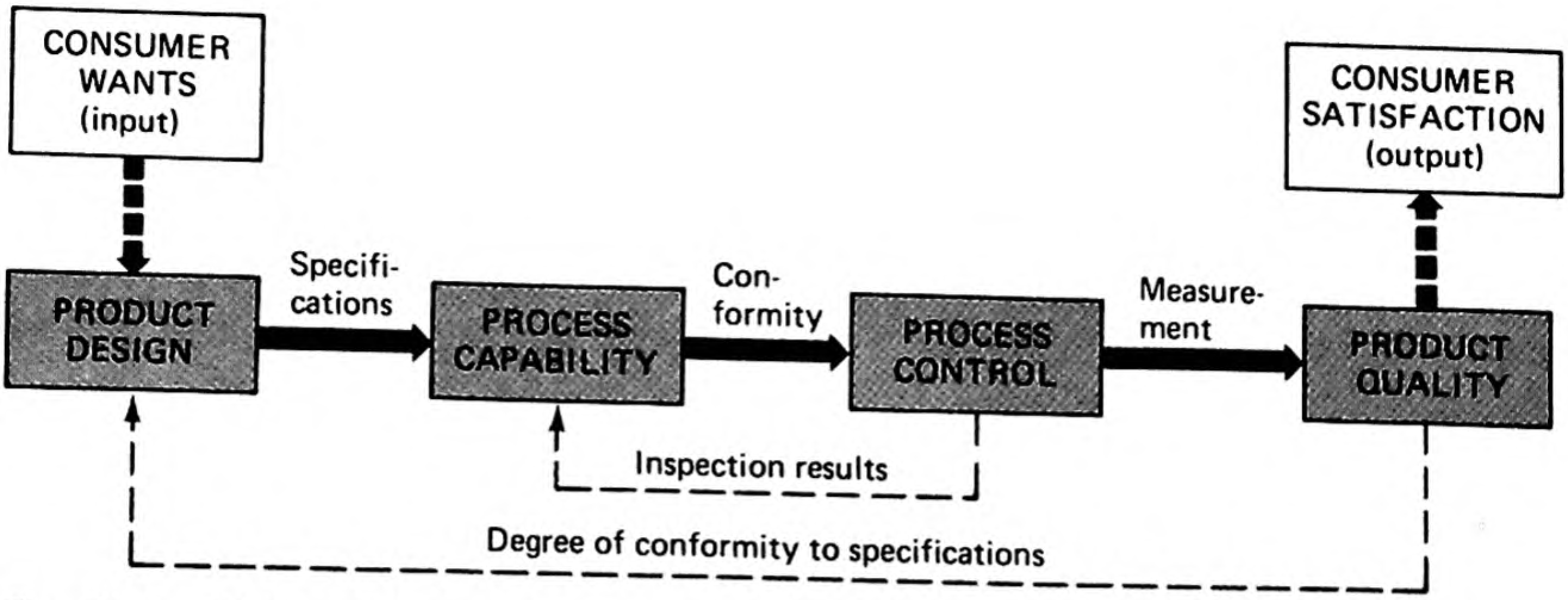


*Fig. 12-1. Phases of the production system that establish the quality of a product through the development of specifications and measurement of conformity to specifications.*

to the needed degree of accuracy must be available and used correctly for inspecting finished goods. Finally, there has to be a means of feedback to correct deviations in the process or to alter the specifications.

### Technical Excellence

The degree of technical excellence built into a product is determined by consumer acceptance. More refined products are necessarily more expensive. It is difficult to find out how much a consumer is willing to pay for greater precision.* The relationship between cost and value as a function of technical excellence is shown in Figure 12-2. A low degree of technical excellence is associated with low production cost and a low value. As technical excellence increases, the cost tends to increase at an increasing rate while value increases at a decreasing rate.

In theory, the ideal level of technical excellence occurs at the point where the cost and value curves are farthest apart. Unfortunately, this point is easier to describe than it is to find. The value individuals place on a product varies widely and fluctuates rapidly. Some people take pride in owning a finely crafted product while others prefer to buy lower priced, lower quality products. Fads and general economic conditions also influence the choice.

*Technical excellence has been rewarded with relatively small but profitable markets in some product lines, such as custom automobiles. Ideally, a customer should be anxious to minimize his total costs. That is, he should recognize that it is to his advantage to pay an extra $30 for a $100 appliance if he can save $75 in service charges over the life of the appliance. But logic is complicated by the customers' lack of knowledge about what constitutes high quality and what repair costs should be anticipated. Most advertising does little to relieve the ignorance. Indeed, some manufacturers may even look at the sale of replacement parts as more profitable than original equipment sales.

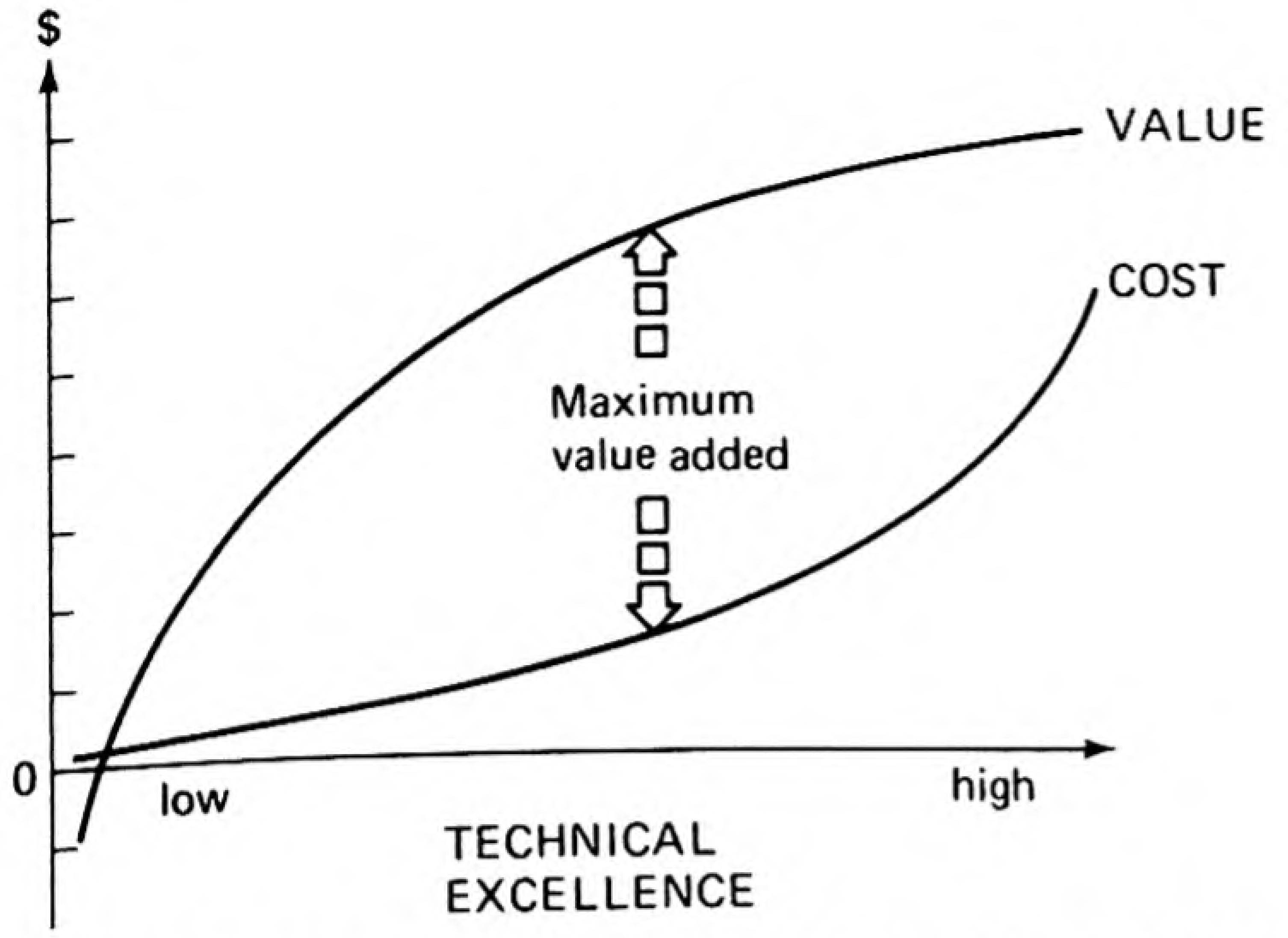


*Fig. 12-2. The general relationship of value and cost to the technical excellence of a product.*

### Excellence of Conformance

In facing the question of higher or lower technical excellence and associated prices, managers must consider the costs of conforming to the design specifications. It is becoming more common to give warranties with such products as automobile batteries, appliances, tires, wristwatches, and boat motors. These guarantees of life or service are cost commitments by the producer. They may provide a competitive edge in marketing, but they have to be supported by a corresponding level of production accuracy to keep warranty compensations within reasonable limits.

The costs of conforming to design specifications are broadly represented in Figure 12-3. Production processes should yield output according to desired specifications, and these processes must be monitored to ensure conformance. A greater degree of conformance is attained at ever increasing costs, but these costs decrease losses due to lack of conformity. Money spent for conformance is a preventive expense. It prevents future losses due to poor quality.

Losses resulting from poor quality can take many forms. We have already observed the external costs of selling nonconforming products, both in honoring guarantees and in loss of future sales. Internal losses are more subtle but just as significant. When a nonconforming product is caught by inspection, it has to be scrapped or reworked with a consequent cost for labor, machine time, materials, and overhead charges. Processes having a low conformance level may have to have a larger capacity. For example, a facility that has to produce 1000 units a day to get 700 good units has capital costs perhaps 20 percent greater than would be needed for a process that produced, say, 10 percent defectives.

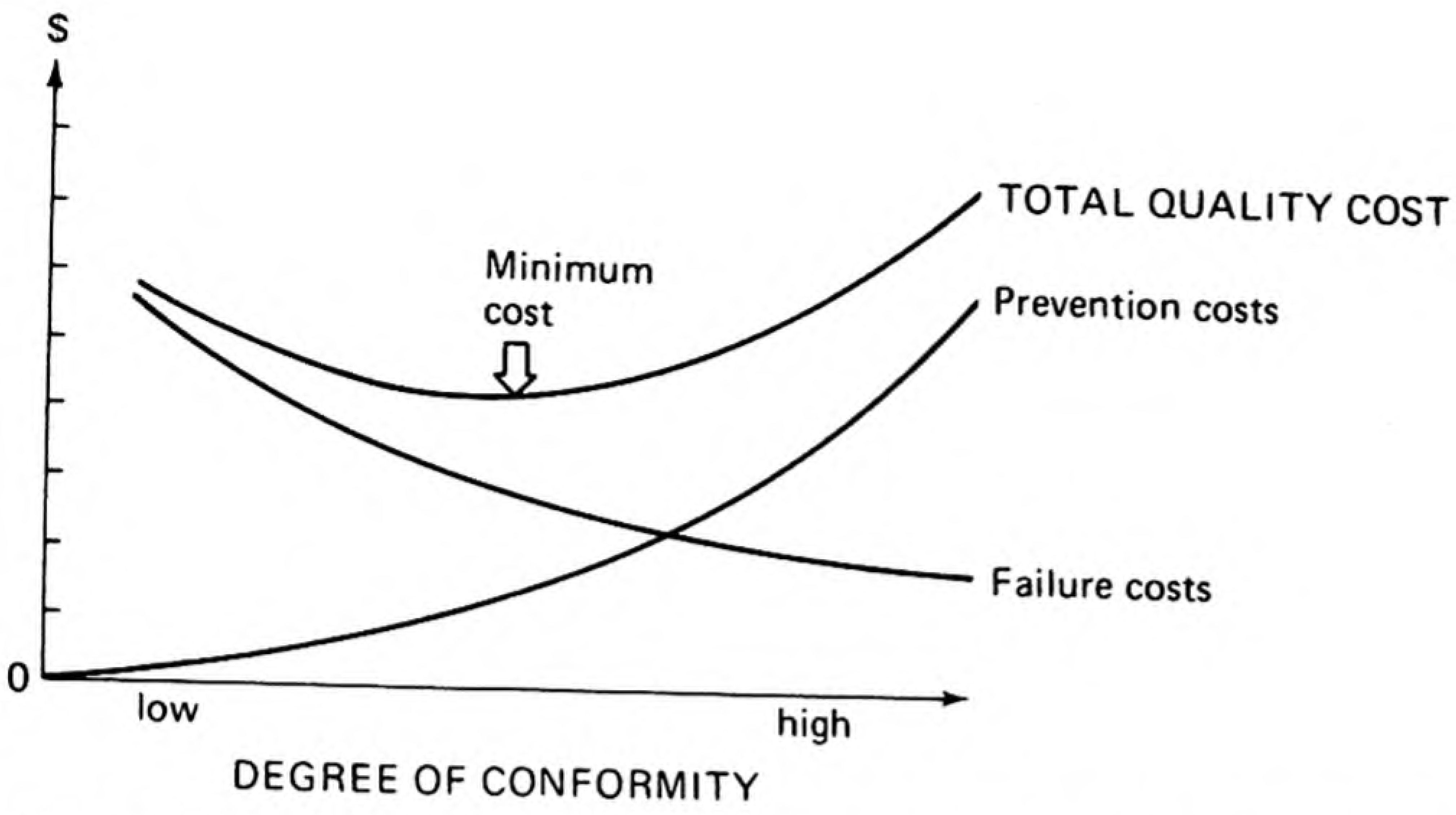


*Fig. 12-3. Total quality cost is the sum of expenditures made to raise product conformity and expenses arising from nonconforming output.*

The costs for preventing failures come from several sources. Any quality assurance program has administration costs and associated overhead charges. Inspection expense includes the wages of inspectors and supervisors, initial cost and maintenance of inspection and test equipment, and laboratory test charges. The time spent in training sessions for staff and workers plus the instruction costs can also amount to major expenditures.

Eventually cost and value considerations lead to the question "how good is good enough?" The query seems open ended, but it has to be answered.

## INSPECTING

Inspecting is a basic action in monitoring output. As used in quality assurance, an inspection compares the accuracy of output with the intended precision of the process. In a typical manufacturing situation, an inspector uses a measuring instrument to determine the exact dimensions of a unit just off the production line. If the actual dimensions fall within the specified range of permissible variation, the product is accepted. If not, it is rejected. Besides identifying individual units that do not conform, the collected results of many inspections reveal the current capability of the process. This information helps to plan methods for reducing or preventing future nonconformance.

### What to Inspect

Almost every type of output deserves some inspection. The purpose of the inspection may be simply to discover what quality is being delivered. More often the purpose is to improve the quality of output.

Inspections are not limited to measuring the dimensions of a unit off the production line. The level of service provided by an organization can be measured from opinions of the people being served. Health inspectors evaluate sanitation. Vegetables, lumber, and many other products are sorted to grade by inspectors. Chemical analyses define the composition of substances. Welds are tested by ultrasonic devices. Building inspectors check safety hazards. People inspect people just as machines inspect machines. Though the methods employed in these examples differ greatly, each is an official, planned effort to measure current conditions or results of present performance.

### When to Inspect

In a production process that converts raw materials to finished products there are many points where inspections can prevent loss. In less extensive processes there may be just a single point, usually the final phase of a project, where an inspection is justified. The simple guiding rule is to perform inspections when the cost of examining is exceeded by the losses avoided by the inspection.

Incoming raw materials or components purchased for future assembly are good prospects for inspection. Faulty inputs discovered at the beginning of a process eliminate refinement costs that would be wasted by continuation of work on an already flawed item. Deliveries from a reputable supplier can be damaged in shipment. Materials from farms and orchards are graded for quality to set the amount of payment and to determine how they should be treated for processing. If the materials are perishable and have to be stored before entering the production process, it may be necessary to reinspect already accepted supplies.

Products that pass through several stages of development are candidates for inspection just before entering a particularly costly or irreversible stage. Objects that are to be gold- or silver-plated should meet specifications before the plating stage. Similarly, inspections held just prior to any coating, encapsulating, or painting can identify defects before they are hidden. Each ingredient in a blend or mix of materials should be up to standard because the whole mix can be ruined by just one substandard ingredient, and it is almost impossible to unmix mixtures such as concrete, paint, cake mixes, lawn seeds, etc.

A final inspection is scheduled at the last stage of the process. A plane is flight tested. A car is road tested. A mechanism is checked to see that it works properly. Food products are sampled for conformance to weight and content specifications. The final examinations protect the quality claims of the producer and build confidence for consumers.

### Where to Inspect

Most inspections take place at the work site. Production workers examine the products they work on, visually inspecting each unit and measuring its dimensions or condition with calipers, scales, gauges, and other devices. Floor inspectors and supervisors roam the work area to check the output of workers and automated machines. Field inspectors travel to construction sites, harvest areas, and other remote locations where work is underway that will later affect the final product. All the inspectors have responsibility for detecting flaws and for immediately initiating corrective actions.

Special inspection facilities are located at points where the inspection needs are concentrated or the needs are particularly serious. Inspection stations are found on loading docks, at funnel points such as a port of entry for customs inspections, at distribution points, and at transfer points in assembly lines. These locations may be equipped with mechanized equipment or special devices to detect critical characteristics.

Testing laboratories have highly qualified personnel and delicate diagnostic equipment for reliable and precise inspections. These labs are frequently independently owned and serve customers from several companies or even from different industries. They specialize in testing technical characteristics such as chemical composition, compressive or tensile strength, structural qualities, health hazards, and length of life. Larger companies may have a testing laboratory as part of their production complex. This proximity reduces the costly problem of transporting items to a remote site for testing.

Advantages gained from the more detailed analysis possible in a laboratory are somewhat offset by delayed results and by the necessity to trace mistakes caught in the lab back to their origin for correction. On-site inspections may not be quite as reliable, but they quickly pinpoint the source of error. In effect, they detect the symptoms of a production illness before the disease affects a large proportion of the output—prevention instead of cure.

### How to Inspect

From the foregoing it might appear that inspections are continuously and extensively necessary for every process. In one respect this view is accurate; a process deserves examination in the same way an artist inspects the picture he is painting: he is aware of the picture's quality as it develops, but only at the end or at critical points does he really study the quality. Two factors limit the amount of inspecting. One is the "big brother is watching you" feeling that workers get when an inspector seems always to be peeking at their work. The other is the cost of inspection. This cost is always substantial, but it can be minimized by choosing the best inspection plan.

Two methods of measuring are used in inspection. The first is called *variables* inspection: measurement of a unit's properties on a graduated, continuous scale, such as inches or pounds. The other method is *attributes* inspection: evaluation of a unit to determine its classification, such as good or bad. An inspector records exact dimensions while inspecting variables. For example, the tolerance specified for a unit might be 0.500 ± 0.001 in., and the inspection would yield dimensions such as 0.501 in., 0.502 in., 0.499 in., 0.500 in., etc. Results of attributes inspections are simply over, under, or within specifications. For example, "go, no-go" gauges are often used to check attributes; one opening in the gauge represents the largest acceptable dimensions and another opening the smallest. If an item being inspected does not fit into the large opening, it is retained for reworking to make it smaller. If it passes through both openings, it is too small to meet specifications and is therefore rejected. If it is "go" through the large opening and "no-go" through the small opening, the item is classified as acceptable.

A few product lines regularly receive 100 percent inspection. This form of inspection is referred to as *screening* and is usually reserved for products that will create a major loss if they are defective. Although the cost of screening is very high, it is routinely applied in some industries, such as aerospace. If screening were conducted for all parts of an automobile, the selling price would be outrageous. Therefore only key assemblies like motors receive 100 percent inspection. The practice of screening larger units of output such as electrical assemblies is reasonable because the cost of making repairs for defective assemblies is much less at the factory than after the assembly has been delivered to a customer. It also helps consumer relations to deliver a product that works.

The economics of 100 percent screening of output for defectives is apparent in a simple example. Assume that a penalty of $10 occurs whenever a defective unit is forwarded. The process by which such units are produced consistently delivers 3 percent defectives. Then for each 100 units produced, three are expected to be defective, and the cost per unit prior to inspection is

$$\frac{3 \text{ defectives}}{100 \text{ units}} \times \frac{\$10}{\text{defective}} = \frac{\$30}{100 \text{ units}} \text{ or } \frac{\$0.30}{\text{unit}}$$

If the cost of inspecting one unit is $0.20, then screening will yield a savings of

$$\frac{\$0.30}{\text{unit}} - \frac{\$0.20}{\text{unit}} = \frac{\$0.10}{\text{unit}} \text{ or } \frac{\$10}{100 \text{ units}}$$

Another form of inspection is *sampling* in which only a few items, samples, are inspected from the total number of items that could be examined. The two main uses of sampling are for process control and for distinguishing acceptable lots from unacceptable lots, where a *lot* is an accounting unit that contains many identical units. *Control sampling* involves the occasional inspection of a unit of output to evaluate the precision being delivered by the process. *Acceptance sampling* is usually associated with the inspection of incoming deliveries and the final inspection of outgoing shipments. Sampling is also used for products that are destroyed by testing, such as fuses. The basis for drawing conclusions about an entire collection of products from the inspection of only a few units in the collection depends on statistical concepts. These concepts are discussed in the next two sections where acceptance sampling and control sampling are explored.

## SAMPLING

Acceptance sampling is conducted to give assurance that internally generated or externally supplied products meet specified expectations. The products may be packed in boxes, barrels, trucks, rolls, or any other natural division of quantity. The divisions are a measure of lot size. Each lot is sampled to judge its conformance with requirements. The result is a recommendation to accept or reject the entire lot.

### Statistical Concepts

One sample could be a single observation taken from a defined set or population. In Chapters 7 and 11 we considered work sampling. One observation of what a worker is doing is a sample of the set of work elements performed by that worker. If several workers are doing the same type of work, the observation is a sample of the work elements performed by all the workers in the given population. A sample could also be a number of observations taken over a period of time about the performance of one worker or a group of workers doing the same type of work.

Sample size refers to the number of observations made during one collection period. For example, the inspection of five items from a shipment of 100 supposedly identical items has a sample size of five and a population size of 100. It is intuitively obvious that a larger sample size, when the population size is constant, has a better chance of revealing the true characterstics of the population. Unless the sample size equals the size of the population, there are occasions when the sampling may yield nonrepresentative results (exception: when every unit in the population is identical, a sample size of one will yield a true identification for the entire population). This risk of false identification is part of the compromise between reliability and cost; the greater expense of going to larger sample sizes must be balanced by a larger loss that would result from a wrong verdict.

In acceptance sampling we are usually interested in *random samples*, observations taken in such a way that every unit in the population has an equal chance of being observed. If a shipment was being delivered on a conveyor belt and every tenth item was inspected, we would *not* be taking a random sample. If an item was inspected every 10 minutes, it would still *not* be random sampling. To achieve randomness, some form of chance number generation is usually employed. The generator could be a container holding numbered slips of paper that represent each unit in the population; a draw shows which unit is to be sampled. It is easier, however, to use published tables of random numbers or to let a computer randomly issue numbers. Randomness gives an equal chance for items to be observed even if the observation is inconvenient, such as the bottom box in a big pile or the last item finished late at night.

It has been suggested that the law of probability is one of the few natural laws that is true anywhere in the universe. We are all familiar with the 50/50 chance of getting a head on each flip of a fair coin; the probability of a flipped coin showing a head is 0.50. Ardent poker players might know that the chance of getting one pair in a fair deal of five cards is 1 in 2.36, or the probability is 0.422; a royal flush averages once every 649,740 deals, a probability of 0.0000015. Such probability statements can also be made for sampling plans. The law of probability allows calculations of the risk of making an incorrect conclusion from the samples taken.

### Sampling Plans

Acceptance sampling plans are designed to provide an economically sound method of identifying product lots which should be accepted without further inspection. The rejected lots are normally subjected to 100 percent screening, called a rectifying inspection. The economy of the plan can be judged by the costs involved. Using again the example that an undetected defective causes a loss of \$10 and the cost of inspecting one unit is \$0.20, the breakeven quality level for the lot is \$0.20/\$10 = 0.02. That is, lots containing less than 2 percent defectives should be accepted because the cost of screening exceeds the cost expected from accepting fewer than two defectives per 100 units. Ideally, then, the sampling plan should have an acceptance probability of 1.0 for lots with fewer than 2 percent defectives and a 0.0 probability of accepting lots with more than 2 percent defectives.

Actual sampling does not meet the theoretical ideal. Physical problems of boredom and fatigue keep actual inspections from delivering complete accuracy. Assumptions about the properties of the population being sampled are not always correct. The samples taken may not be truly random due to unavoidable conditions. And, most significantly, there is some probability that the plan will reject an acceptable lot or accept a lot that should have been rejected. However, different types of sampling plans have been developed to produce realistic appraisals at a reasonable expense. To select a sampling plan we must answer four questions:

1. What is the maximum percentage of defectives in a lot that makes it definitely unacceptable (termed the *lot tolerance percentage defective*, LTPD)?
2. What is the maximum percentage of defectives in a lot that should be accepted (known as the *acceptable quality level*, AQL)?
3. What probability of accepting an actually nonacceptable lot is the consumer willing to risk (known as the *consumer's risk*)?
4. What probability of rejecting an actually acceptable lot is the producer willing to risk (called the *producer's risk*)?

Answers to these four questions lead to the development of a curve like that shown in Figure 12-4, which displays the characteristics of one sampling plan. In the plan shown, the probability of accepting a lot with 12 percent defectives is 0.10 and the probability of rejecting a lot with 2 percent defectives is 0.05.

Tables and charts are used to select the most appropriate sampling plan for a given application. Collections of standard plans have been published[1] for both variables and attributes sampling. Special plans using multiple or sequential sampling have been designed to reduce the amount of sampling necessary to maintain essentially the same producer's and consumer's risks. Thus the design of the plan is undeniably important, but the success of the sampling operation depends more on how well it is managed. "What, when, where, and how" to inspect is more critical than "which way" to sample.

## CONTROL CHARTS

After considering how sampling can be used to help decide whether to accept or reject a lot, it is logical to ask why there should even be a question about the quality of lots. Why not just make sure a process always produces product lots of uniform, stated quality? This is, of course, the goal of quality control programs. Quite often the goal is achieved. Acceptance sampling guards against unachieved process quality goals, as well as any damage to satisfactory products that

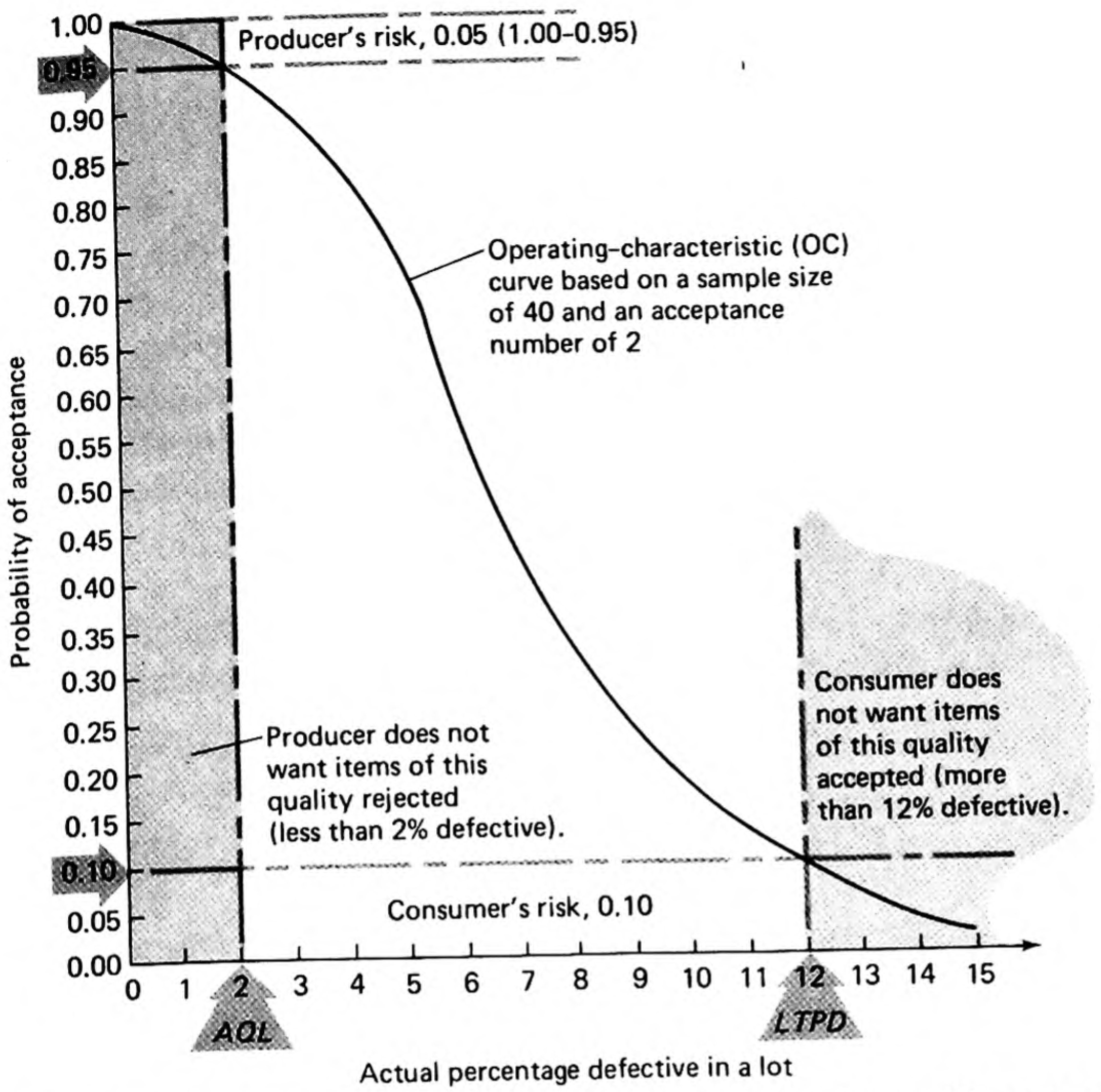


*Fig. 12-4. Every sampling plan can be represented by an "Operating Characteristic" (OC) curve. The shape of the curve depends on the ratio of the sample size to the lot size and the desired consumer's and producer's risks. The given OC curve is designed for sampling lots with a large population by using a sample size of 40 items. A lot is rejected when more than 2 defectives are discovered in a sample. The discrimination of this plan (its ability to accurately detect good or bad lots) would be increased by increasing the sample size with a proportionate increase in the acceptance number (the maximum number of defects that can be found in a sample which still allows the lot to be accepted). This increase in discrimination affects the OC curve by moving it to the left in the chart and making it steeper.*

occurs after the production process. So acceptance sampling will remain a needed tool for quality assurance.

Essentially the same sampling procedures can be used for process quality assurance. Suggestions for conducting inspections and the statistical concepts of sampling already discussed are generally applicable to process control. It is the purpose of the inspecting and sampling that differs. The main purpose of process control is to detect changes in a stable process that affect the quality of the output. Detection depends on previously discussed (and additional) statistical concepts for monitoring performance.

### Concepts of Statistical Control

Some variation in output is certain to occur in any process that produces measurable products. We previously referred to these properties as *variables*, and they are characterized by dimensions such as length, weight, and volume. Changes in dimensions can be traced to many sources. As the sharpness of a cutting tool decreases or vibrations in a machine increase, the units produced with the dull tool and shaky machine will be less exact. Slight changes in the composition of raw materials can affect the finished product. At any stage of the conversion of inputs into outputs, turnover or other changes in the work force can cause temporary variations in quality. The patterns of these variations often suggest clues as to what is causing the trouble.

Two descriptive statistics about the variation of variables are the *mean* and *range*. The arithmetic mean is traditionally represented by $\overline{x}$ (x-bar) and is calculated as

$$\overline{x} = \frac{\Sigma x}{n} = \frac{\text{sum of the observed values in a sample}}{\text{number of observations}}$$

The range (R) is the difference between the maximum and minimum values observed in one sample;

$$R = x_{\text{max}} - x_{\text{min}}$$

To illustrate the use of these statistics, we can observe their application in checking the performance of a packing operation. In this operation, crabmeat is packed by hand into 5-pound containers. The actual weight put into the cans is slightly over 5 pounds to compensate for the weight lost after the meat dries. Five cans are randomly selected from the output of each weighing station at the end of each day and weighed. These five measurements are considered to be one sample. The mean of each sample is x and the range is R. A record of net weights obtained from one station is given in Table 12-1.

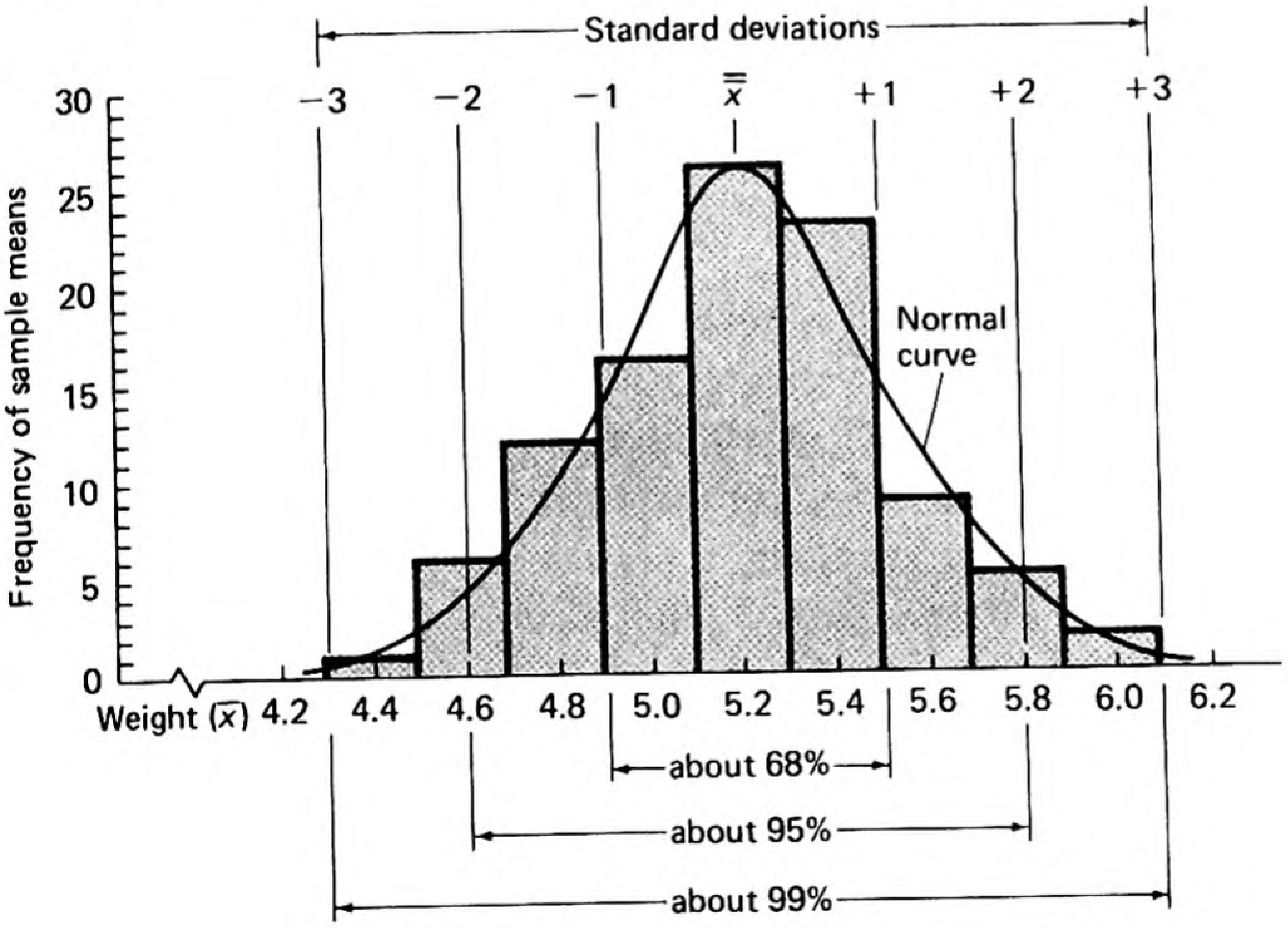
Just a quick look at the means of the samples in Table 12-1 leads to a suspicion that something went wrong on days 9 and 10. The question then arises whether this variation is just part of the natural rhythm of ups and downs or whether it indicates that something has occurred to change the mean. This question is answered by statistical reference to the distribution of previously experienced measurements from the same weighing process.

Variables are usually assumed to follow a pattern of dispersion known as the *normal* distribution. This particular pattern is widely used in statistical analyses.

TABLE 12-1. SAMPLING RECORD OF WEIGHTS OBTAINED AT ONE WEIGHING STATION. THE RECORDED NUMBERS INDICATE THE NET WEIGHT TO THE NEAREST OUNCE ABOVE 5 POUNDS. THAT IS, A TABLE ENTRY OF 6 MEANS THE NET WEIGHT OF THE CRABMEAT IN THE CONTAINER IS 5 POUNDS AND 6 OUNCES.

| SAMPLE (Date) | WEIGHT MEASUREMENT (Ounces over 5 Pounds) | | | | | SUM | $\bar{x}$ | R |
|---|---|---|---|---|---|---|---|---|
| 11/1 | 4 | 5 | 5 | 6 | 5 | 25 | 5.0 | 2 |
| 11/2 | 5 | 5 | 5 | 5 | 4 | 24 | 4.8 | 1 |
| 11/3 | 6 | 5 | 5 | 6 | 6 | 28 | 5.6 | 1 |
| 11/4 | 5 | 6 | 4 | 5 | 6 | 26 | 5.2 | 2 |
| 11/5 | 5 | 5 | 3 | 4 | 6 | 23 | 4.6 | 3 |
| 11/6 | 6 | 4 | 6 | 6 | 5 | 27 | 5.4 | 2 |
| 11/7 | 5 | 5 | 5 | 5 | 5 | 25 | 5.0 | 0 |
| 11/8 | 5 | 5 | 6 | 6 | 5 | 27 | 5.4 | 1 |
| 11/9 | 6 | 7 | 6 | 6 | 8 | 33 | 6.6 | 2 |
| 11/10 | 6 | 7 | 6 | 7 | 6 | 32 | 6.4 | 1 |

It is a symmetrical, bell-shaped curve that describes the distribution of measurements found in a population, as suggested by Figure 12-5 which is based on 100 samples from one crabmeat weighing station. The bars indicate the number



Theoretical percentages under the normal curve

*Fig. 12-5. The bars in the chart form a "histogram" that displays actual sample means collected during 100 days of observating one crabmeat weighing station. The superimposed curve shows the frequency of weights that would occur if the process exactly followed the theoretical normal distribution. The base of the curve is divided into six equal segments, each representing one standard deviation. About 99% of the process observations represented by the normal distribution should fall within three standard deviations on either side of the process mean,* $\bar{\bar{x}}$.

of times each sample mean ($\bar{x}$) was recorded during the 100-day period. The curve imposed on the bars is the theoretical normal distribution, and apparently is a good representation of the tabulated means.

At the center of the normal curve in Figure 12-5 is the process mean denoted by the symbol $\bar{\bar{x}}$ (x-double bar). It is the average of all the sample means as calculated from the expression

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots + \bar{x}_N}{N}$$

where $N$ = the number of samples and $\bar{x}_1 \ldots \bar{x}_N$ are sample means

The base of the curve is divided into equal segments, each one a *standard deviation* unit. These deviation units get the "standard" title because they always account for the following percentages of the area under a normal curve:

- $\bar{\bar{x}} \pm 1$ standard deviation contains 68.26 percent of the area under the curve
- $\bar{\bar{x}} \pm 2$ standard deviations contain 95.46 percent of the area under the curve
- $\bar{\bar{x}} \pm 3$ standard deviations contain 99.73 percent of the area under the curve

When it can be assumed that the population of sampled values is normally distributed, the statements about standard deviations can be generalized by adding the word "approximately" and changing "area" to "population."

We are interested in the statistical properties of the normal distribution because they provide the basis for deciding when a process is out of control. We have observed that 99.7 percent of normally distributed observations about a process should be accounted for by the measurements bracketed by three standard deviations on both sides of the process mean. Equivalently, by chance alone an observation will be outside these limits only three times in 1000. Therefore, if we find an observation (a sample mean) outside these limits, we have strong reason to expect that it did not occur just by chance; there is probably an assignable cause why it varied so much.

Books about statistics or quality control can be consulted for formulas to calculate the standard deviation and different ways to draw conclusions about process control from statistical inferences. Our attention will be restricted here to a simplified procedure for calculating process control limits. This procedure is recommended for preliminary analysis of data. As more data become available, more refined statistical measures may be substituted to obtain closer control.

In most industrial applications involving variables, control limits can be calculated by using the range ($R$) as a measure of variation. The factors which convert the mean range ($\overline{R}$) to control limits are given in Table 12-2. Before the factors can be used the mean range must be calculated as

$$\overline{R} = \frac{R_1 + R_2 + \ldots + R_N}{N}$$

where $N$ = number of samples and $R_1 \ldots R_N$ are all the individual sample ranges

Then the control limits can be established for both the process mean (to check the variation of the sample means) and the process range (to check the variation in sample ranges). Three standard deviation limits for the process mean are equal to $\overline{\overline{x}} \pm A\overline{R}$. The equivalent limits for the range are

3-standard deviation upper limit for the process range = $B\overline{R}$
3-standard deviation lower limit for the process range = $C\overline{R}$

Note that the appropriate value of A, B, or C is selected from Table 12-2 according to the sample size.

TABLE 12-2. FACTORS FOR ESTABLISHING 3-STANDARD DEVIATION CONTROL LIMITS BASED ON THE MEAN RANGE ($\overline{R}$) OF SAMPLES. FACTOR A IS USED FOR BOTH UPPER AND LOWER LIMITS OF $\overline{x}$ CHARTS. FACTORS B AND C ARE USED RESPECTIVELY FOR THE UPPER AND LOWER LIMITS OF R CHARTS.

| SAMPLE SIZE | FACTOR A | FACTOR B | FACTOR C |
|---|---|---|---|
| 2 | 1.880 | 3.268 | 0.000 |
| 3 | 1.023 | 2.574 | 0.000 |
| 4 | 0.729 | 2.282 | 0.000 |
| 5 | 0.577 | 2.114 | 0.000 |
| 6 | 0.483 | 2.004 | 0.000 |
| 7 | 0.419 | 1.924 | 0.076 |
| 8 | 0.373 | 1.864 | 0.136 |
| 9 | 0.337 | 1.816 | 0.184 |
| 10 | 0.308 | 1.777 | 0.223 |
| 12 | 0.266 | 1.716 | 0.284 |
| 14 | 0.235 | 1.671 | 0.329 |
| 16 | 0.212 | 1.636 | 0.364 |

### $\bar{x}$ and R Control Charts

Statistical control limits are the basis for quality control charts. The format of a variables control chart has a vertical scale for the sample measurements and horizontal divisions to show when the sample was taken. After setting up the scales, an operator or inspector records sample data as dots on the chart. When sufficient data have been recorded to prove that the process is relatively stable, mean values and control limits are calculated. These calculations are the basis for drawing three parallel lines on the chart; the center line represents the process mean bracketed by upper and lower control limits.

Figures 12-6 and 12-7 show $\bar{x}$ and R charts for the crabmeat-weighing operation. The measurements given in Table 12-1 provide the 10 charted samples. Assuming the 100 samples which contributed to the histogram in Figure 12-5 produced a process mean of 5.2 and the associated mean range from the same data was 1.56, then the control limits are

$$\begin{aligned}\bar{\bar{x}} \pm A\bar{R} &= 5.2 \pm (0.577)(1.56)\\ &= 5.2 \pm 0.9\end{aligned}$$

where A is based on a sample size of 5
or
upper control limit for sample means = 6.1
lower control limit for sample means = 4.3
and
upper control limit for sample ranges = $B\bar{R} = (2.114)(1.56) = 3.3$
lower control limit for sample ranges = $C\bar{R} = (0.000)(1.56) = 0$

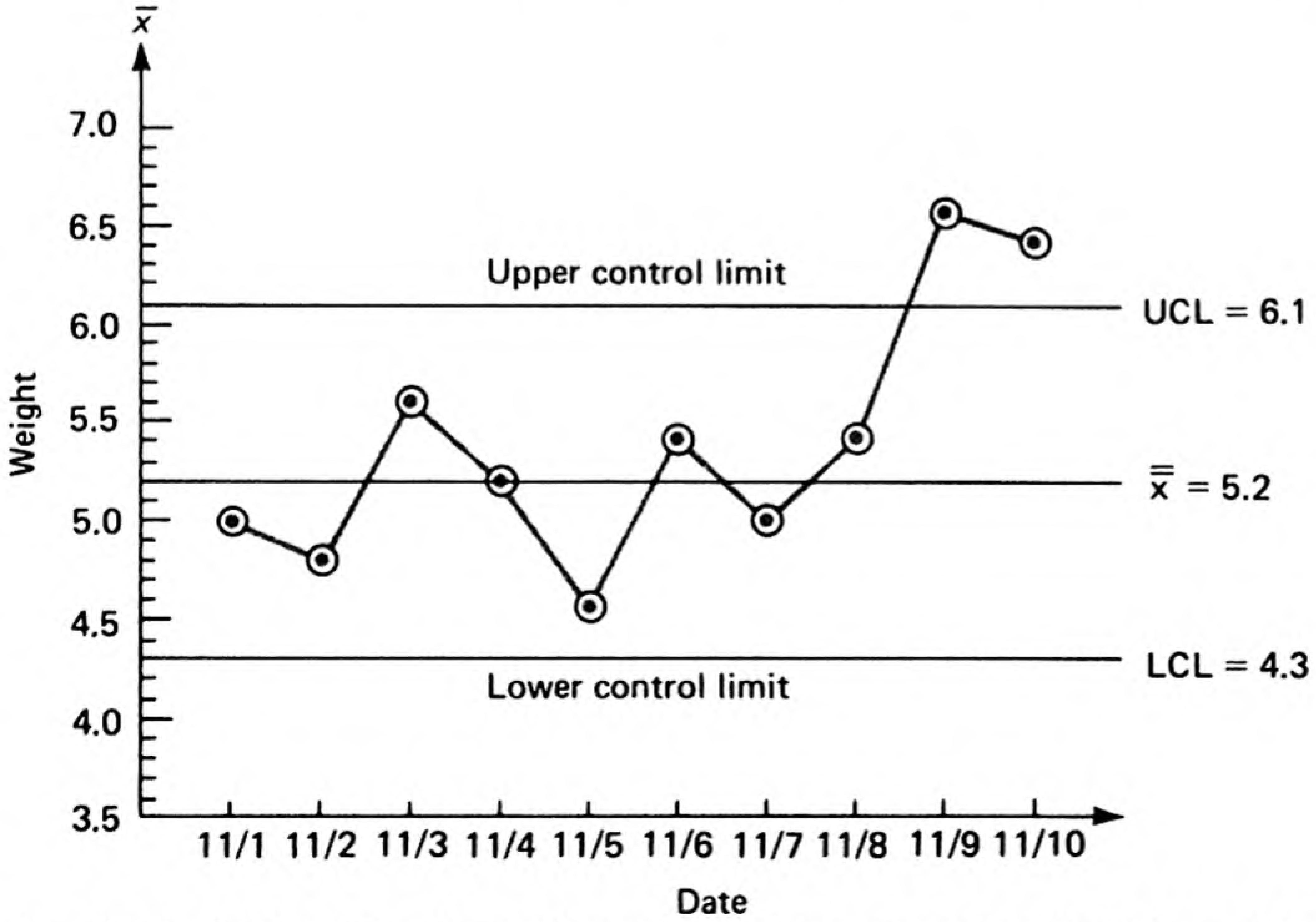


*Fig. 12-6: $\bar{x}$ chart for the crabmeat weighing operation based on data from Table 12-1. The last two sample means are outside the upper control limit.*

Both $\bar{x}$ and R charts are needed to evaluate process control. The $\bar{x}$ chart indicates changes in the level of the process while the companion R chart detects changes in the variability of the process. Either or both charts can signal trouble. For example, the variation *between* samples indicated by the $\bar{x}$ chart may be large while the variation *within* samples remains relatively constant. This condition occurs in the example of the crabmeat-weighing operation. The sudden jump in sample weights on dates 11/9 and 11/10 in Figure 12-6 is a definite cause for alarm, but these same samples show no indication of unusual variability in Figure 12-7 for the weights taken on either critical day. From this condition the logical conclusion is that something has affected the level of performance while there has been no change in the capability of the weighing operation.

A change in capability of a process is considered more serious than a change in the level. To regain control over the level of performance it may take only a simple adjustment such as a new machine setting. A decline in process capability often portends more expensive corrective measures, such as a major repair or even buying a replacement machine to reach the desired output consistency again.

In our crabmeat-weighing example, the cause of the abrupt rise in the weight could have been a new type of container, with no compensation for the change between the weights of the new and old containers. But evidently the capability of the operator to keep the net weights consistent was not affected. If the variability had occurred in the range, it would have suggested a more dangerous fault such as inaccurate scales or an incompetent operator.

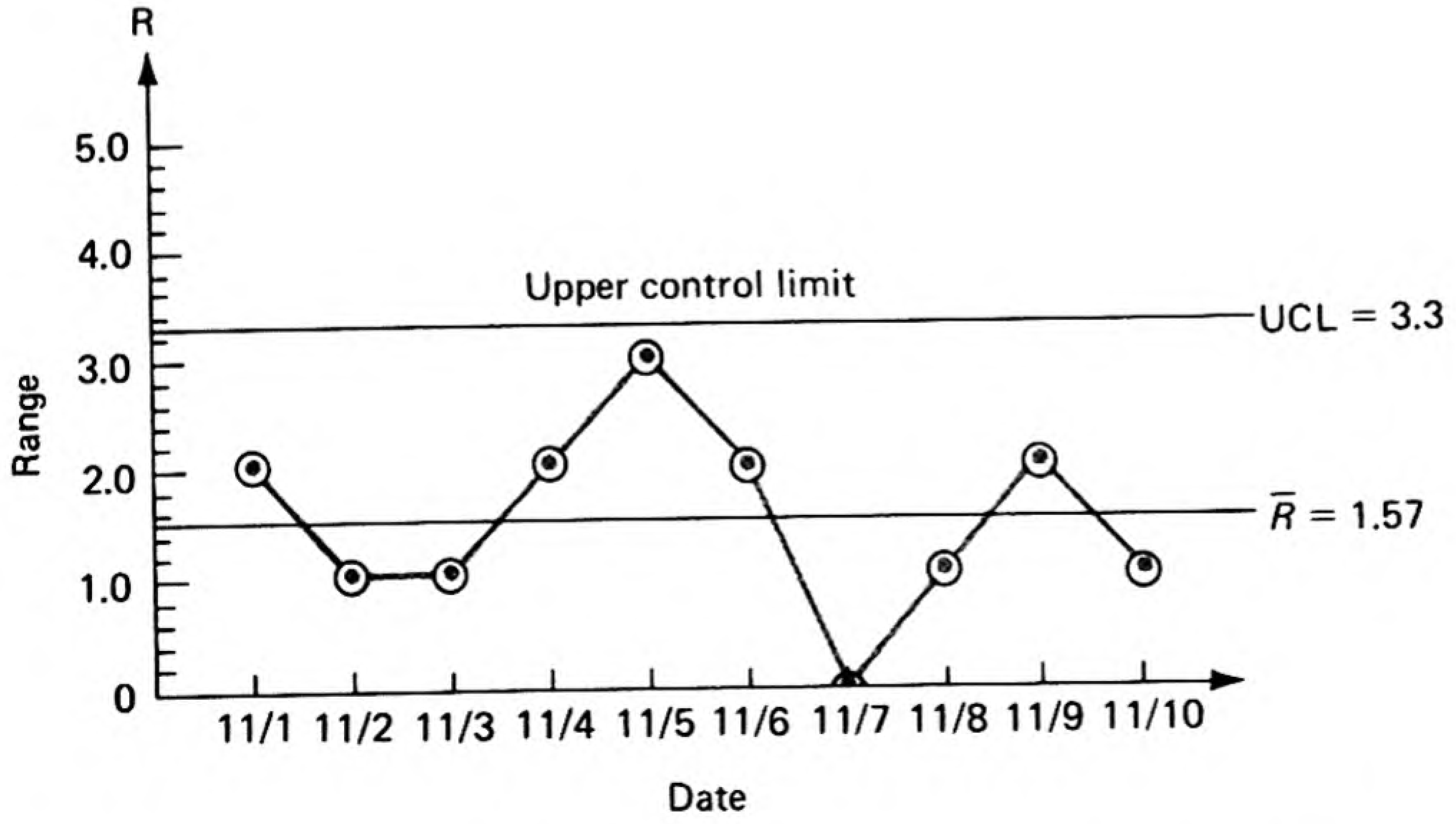


*Fig. 12-7. R chart for the crabmeat weighing operation based on data from Table 12-1. The range of all samples shown is within the control limits.*

### Control Charts for Attributes

The quality of some products is better described by attributes classification than by measurements of variables. As noted in our discussion of acceptance sampling, an attributes inspection classifies a product in one of two states: acceptable or unacceptable. By this classification system a process is frequently rated according to the fraction of its output that is defective. A *p chart* is used to monitor the proportion defective.

Control limits have the same meaning and purposes for p charts as for $\bar{x}$ and R charts. All are constructed similarly. The process mean ($\bar{p}$) for the p chart is the average proportion defective found from all the observations of the process. The 3-standard deviation control limits are calculated from the expression

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where $\bar{p}$ = the mean proportion of defectives
$n$ = the sample size

TABULATION OF FRACTION DEFECTIVE DATA

| **Sample number** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample size ($n$)** | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 750 |
| **Number defective** | 4 | 3 | 6 | 5 | 6 | 4 | 5 | 3 | 4 | 2 | 3 | 1 | 1 | 2 | 1 | 50 |
| **Proportion defective ($p$)** | .08 | .06 | .12 | .10 | .12 | .08 | .10 | .06 | .08 | .04 | .06 | .02 | .02 | .04 | .02 | |

$\bar{p} = \frac{50}{750} = 0.067$

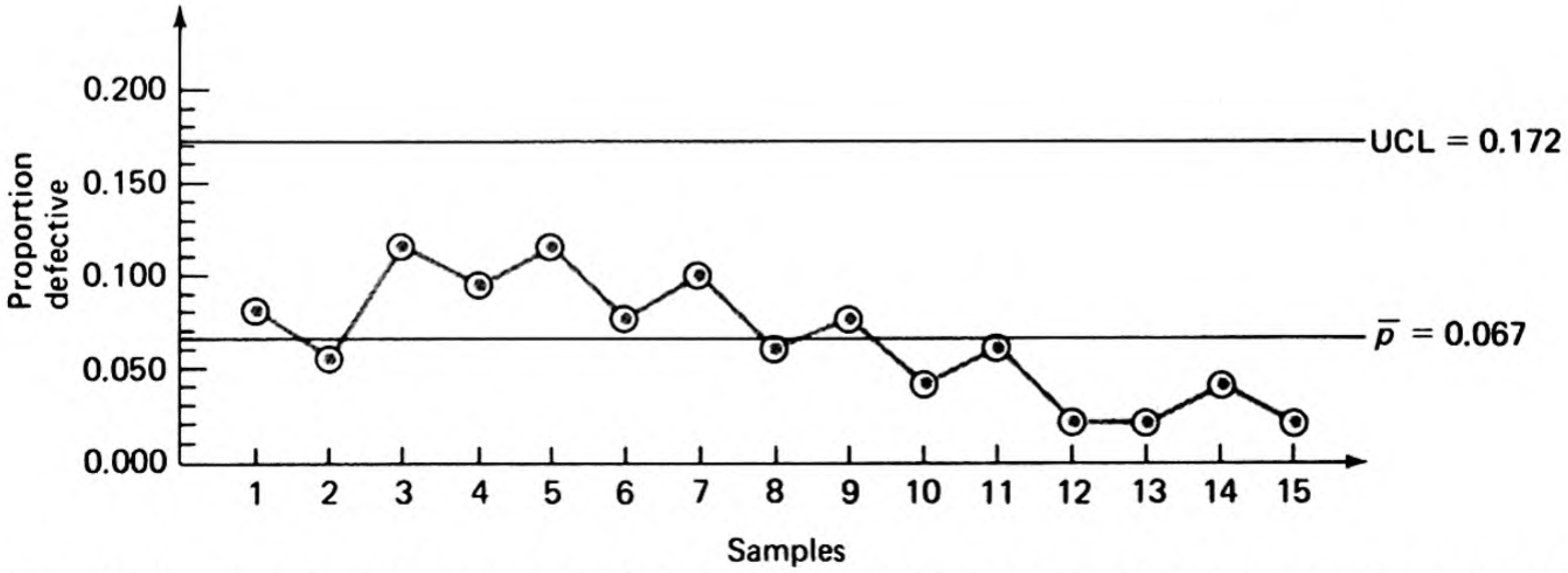


*Fig. 12-8. A p chart for control of attributes based on the fraction defective found in 15 samples.*

This formula is based on a binomial distribution instead of the normal distribution used for variables. The binomial distribution better describes the binary nature of the "acceptable-defective" classification system.

An application of a p chart is illustrated in Figure 12-8. Several samples from the process are inspected each day. Fifty items are included in each sample. The fraction of each sample found defective by an inspection is recorded on the chart as a dot. The mean proportion from the fraction-defective data is computed to be 0.067 and is registered as the centerline of the chart. Then the control limits are calculated as

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.067 \pm 3\sqrt{\frac{0.067 \times 0.933}{50}} = 0.067 \pm 0.105$$

Consequently, the upper and lower control limits respectively are 0.172 and 0.0. It is apparent that all the samples are well within the control limits. In fact, a manager should examine the low proportion of defectives in the last few samples to see if an assignable cause can be found for this period of excellent performance.

### Moving-Range Control Chart

The quality of performances other than production work can also benefit from the application of control charting. In Chapter 5 we observed different methods of forecasting and the importance of accurate predictions. The performance of any forecasting method should be checked continuously to see how well the predictions match actual events. A graph comparing forecasted and actual demands provides a neat visual record of forecasting accuracy. By adding control limits to the graph we have a record of past performance plus a signaling device that alerts us to changes that may be developing.

Essentially the same statistical concepts support both forecasting and production control charts. We will consider control charting for only one forecasting method, moving averages, but a similar treatment is possible for other methods. Recall that in moving-average forecasting, the prediction for the next period is obtained by averaging the actual demands for a given number of periods from the immediate past. Thus, in a three-period moving-average forecast, the prediction for the next period is the average value experienced during the last three periods. The difference between the actual and the forecasted values is called the *forecasting error.* Then the difference between two successive forecasting errors is known as the *moving range* (MR), which provides the name of the control chart for forecasting errors. The construction of an MR chart is shown in Figure 12-9

Control limits for moving-range charts are developed similarly to R charts for variables control. The mean moving range, $\overline{\text{MR}}$, is calculated according to

$$\overline{MR} = \frac{MR_1 + MR_2 + \ldots + MR_N}{N}$$

where $N$ = total number of forecasts with individual values of $MR_1 \ldots MR_N$

There are no negative MR values because all the differences between successive forecasting errors are treated as positive numbers—the *absolute value* of the difference. Upper and lower contol limits that bracket the zero deviation centerline are equal to $\overline{\text{MR}}$ multiplied by 2.66. The resulting limits represent three standard deviations on both sides of the mean forecasting error and are interpreted as allowing about 3 in 1000 errors to be outside the limits by chance alone. Therefore, whenever several plotted points of forecasting error cluster near a limit line or when one crosses it, the forecaster is alerted to a potential shift in the demand pattern.

### Application of Control Charts

A great variety of control charts are used in addition to the types we have considered. All of them rest upon proven statistical theories, are relatively simple to use, and provide the advantages obtainable from visual records of performance. They also require time and money to maintain. Consequently they should only be used when there is a real need. When a process is obviously in trouble, closer control by any means is warranted. As conditions improve, the frequency of sampling can be decreased. All inspection can cease if the process proves reliable, but more likely occasional p-chart samples should be employed to check the quality of several key attributes. In case the process capability deteriorates, the more sensitive $\bar{x}$ and R charts can then be applied.

The way a control chart is maintained and acted upon affects its worth. When charts are outdated or their signals are disregarded, workers soon become disillusioned with the quality assurance program. It is better not to use a chart than to neglect it because its unattended presence just advertises the lack of concern by management. Conversely, a prominently displayed, correctly kept chart can be a strong psychological incentive for better performance.

The choice of sample size, frequency of sampling, type of sampling, and which

COMPILATION OF MOVING AVERAGE FORECASTS AND THE MOVING RANGE FOR PREDICTIONS BASED ON THREE DEMAND PERIODS

| Date | Actual demand | 3-period moving average forecast | Forecasting error | Moving range (MR) |
|---|---|---|---|---|
| Oct 8 | 180 | | | |
| 15 | 164 | | | |
| 22 | 162 | | | |
| 29 | 151 | 169 | 18 | |
| Nov 5 | 143 | 159 | 16 | 2 |
| 12 | 158 | 152 | −6 | 22 |
| 19 | 154 | 151 | −3 | 3 |
| 26 | 160 | 152 | −8 | 5 |
| Dec 3 | 172 | 157 | −15 | 7 |
| 10 | 178 | 162 | −16 | 1 |
| 17 | 188 | 170 | −18 | 2 |
| 24 | 174 | 179 | 5 | 23 |
| 31 | 172 | 175 | 3 | 2 |
| Jan 7 | | 178 | | |
| | | | | 67 = Total |

Mean moving range = $\overline{MR} = \frac{67}{9} = 7.44$

Control limits = ± 2.66 × 7.54 = ± 19.80

MOVING RANGE CONTROL CHART

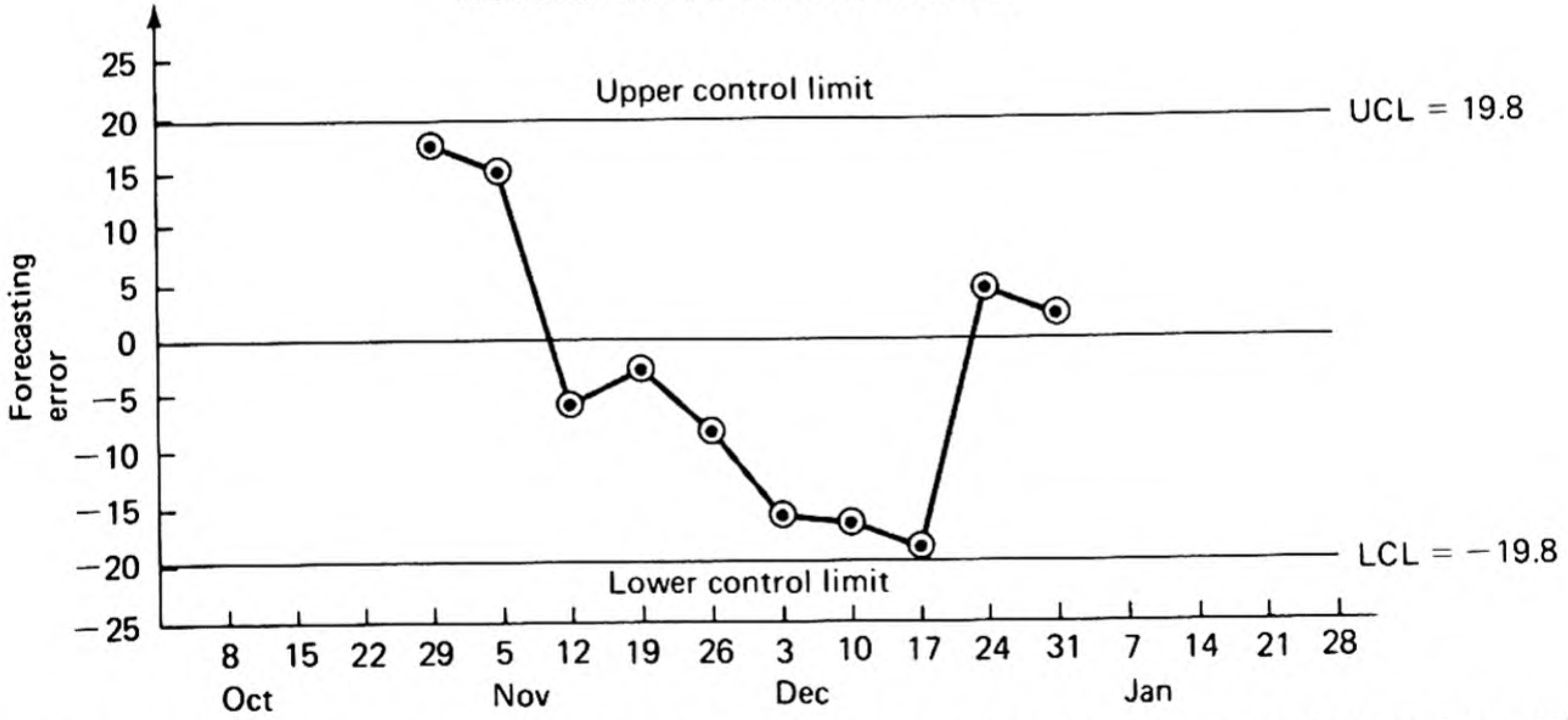


*Fig. 12-9. Moving average forecasts and the moving range control chart. Actual demand for three periods must be known to produce the first three-period moving average forecast. Thus, the forecast for Oct. 29 is equal to* $\frac{180 + 164 + 162}{3} = 169$*. The difference between this forecast and the actual demand (169 − 151 = 18) is the forecasting error and is entered on the control chart at the Oct. 29 date. Such errors can be plus or minus, but the moving range is the absolute value of the difference between consecutive forecasting errors (the difference is always taken as a positive number).*

*The center line of the chart represents zero deviation between forecasted and actual demand. It is bracketed by the control limits. These limits are equal to ±2.66 × 7.44 = ±19.8. Future forecasting errors are plotted as they become known. If they fall randomly above and below the zero deviation line within the control limits, the level of past predicting accuracy can be expected to continue.*

control limits to use depend on specific applications. A manager relies on his experience, understanding of statistical control, and common sense to decide. For instance, it would be absurd to use control limits that let a process appear to be under control while producing products that do not meet contracted specifications.

Much can be learned from carefully observing the pattern of plotted points still inside control limits. Informal rules are often used to identify a trend that suggests a process may be nearing a critical state. The "rule of seven" indicates a process should be investigated for an underlying cause of poor behavior when seven points in a row appear above or below the mean. Other "rules" suggest close scrutiny when two consecutive points are very near the control limit and when a run occurs of five successively higher or lower points. Every clue is worth noting because high quality is difficult to obtain and even harder to maintain.

## QUEST FOR QUALITY

To be effective, monitoring must be more than a collection of inspecting procedures and statistical interpretations; it has to be a way of thinking, a continuing concern. It has been said that quality is everybody's business. Supervisory level managers have the main responsibility for keeping everyone involved.

Supervisors are assisted in their quest for quality by several departments. In a manufacturing organization, product specifications are usually set by the engineering department. The "specs" reflect advice from the purchasing department regarding standards to expect from suppliers and forecasts from the sales department about customers' expectations. Personnel in the manufacturing department confirm that production requirements are realistic and are on call to help when difficulties arise. Frequent causes of low quality and common remedies are listed below.

| | CAUSE OF LOW QUALITY | REMEDY TO IMPROVE QUALITY |
|---|---|---|
| 1. | Workers not understanding what is expected of them | Teach quality requirements and the reasons for the requirements |
| 2. | Lack of ability | Instruct operators how to improve ability or have them switch jobs if necessary |
| 3. | Carelessness | Institute proper training and supervision |
| 4. | Defective materials or equipment | Establish better inspection of materials or provide for improved equipment and better equipment maintenance |

The inspection department assists the supervisors by providing data about current output quality and specific suggestions about feasible improvements. Supervisors should feel free to seek help from all quality-conscious departments, and the departments should recognize that quality is ultimately created on the factory floor.

### Involvement Programs

A belief that concern for quality should be shared by everyone in an organization has led quite naturally to company-wide programs seeking total involvement. Such attempts toward involvement are popularly known as *participative management*. Where these programs have succeeded, they have increased the interest and morale of the work force and have usually improved the quality of the product.

The *zero defect* (ZD) program introduced in the aerospace industries in 1962 has been notably successful in obtaining involvement and higher output quality. The aim of the program is aptly described by its name: ZD means *no* defects. It emphasizes prevention instead of cure to get a job done correctly the first time, every time. It relies on the pride of workers to identify error-prone situations with the assumption that the people best prepared to eliminate errors are those who create them.

*Error cause removal* is a key feature of a ZD campaign. Employees are encouraged to sign pledge cards signifying an intent to reduce errors. Suggestions are solicited to help identify areas where mistakes can occur. Supervisors quickly follow up each suggestion to investigate its worthiness and to provide a remedy when necessary. Pins, plaques, dinners, and certificates honor those who contribute the most. "Days without errors" scorecards are posted. Top managers speak at mass meetings, and supervisors report on progress at group get-togethers. The high motivation promoted early in a ZD program is difficult to sustain, but the recognition given to the importance of quality production has lasting benefits.

In Japan a unique movement has united millions of employees in a common pursuit of quality production. It is called the *QC circle*, QC standing for quality control. The first circles were started in 1962 and now number 400,000 with over 4 million workers participating. A QC circle is composed of a group of production workers and foremen who voluntarily cooperate to solve production-quality maintenance problems. No one is forced to join a circle. After one is formed, it is officially recognized and becomes part of the national organization. Though circles have a grass-roots outlook, top management provides substantial backing and encouragement. Companies help their QC circles actively participate in regional and national conferences.

A first-line supervisor usually leads a QC circle. Meetings are typically held once or twice a month in the evening. During the meeting common problems are discussed, plans are made to solve the problems by collecting data, and recommendations based on the analyzed data are prepared for presentation to appropriate managers. Circle members use control charts, cause-and-effect diagrams, histograms, and other quality-control techniques to develop solutions.

An indication of the significance of QC circles to Japanese industries is reported by Professor Kaoru Ishikawa of the University of Tokyo. He estimates that savings resulting from individual QC circles range from $250 to $560,000 per year with the average amount about $100,000. A poll of 1566 companies in Japan showed 91 percent have QC circles. It is probably not possible for all countries to follow exactly the same approach the Japanese have developed so successfully, but their example has many features worth following.

### More Monitoring

Greater attention is being given to quality control today than ever before. Some critics say contemporary quality is dropping and place the blame on a lack of pride and craftsmanship in today's employees. They also blame high-speed assembly lines where it is difficult to catch mistakes before the product is out of the factory. Blame even spreads to managers accused of being more interested in quantity rather than quality.

Other critics feel that modern quality is as good or better than ever; the problem is that customers simply expect more than ever before. Informed buyers, who compare quality claims on TV with actual product performance, are sometimes disgruntled by that performance. And now they have efficient ways to pass along their complaints through consumer-protection programs. Most managers would agree that higher quality at lower prices is surely commendable, and even the threat of legal suits seeking compensation for poor quality is stimulating in the long run, but the immediate problems of meeting these greater expectations are formidable.

The present thrust is toward improved monitoring during a product's engineering, manufacturing, and customer-use phases. Quality starts with a competent design supported by tests and reviews. Monitoring during manufacturing should be policed by an independent group, not the group responsible for production. In the customer-use phase, monitoring traditionally has ended with installation or maintenance support activities conducted by the organization's customer service department. A recent trend, particularly in automobiles, aircraft, and electronics, has been to extend monitoring over a product's reasonable service life. Consequently, firms are now striving for a level of product reliability that is reasonable in cost for product service guarantees and is attractive in price for consumer warranty protection.

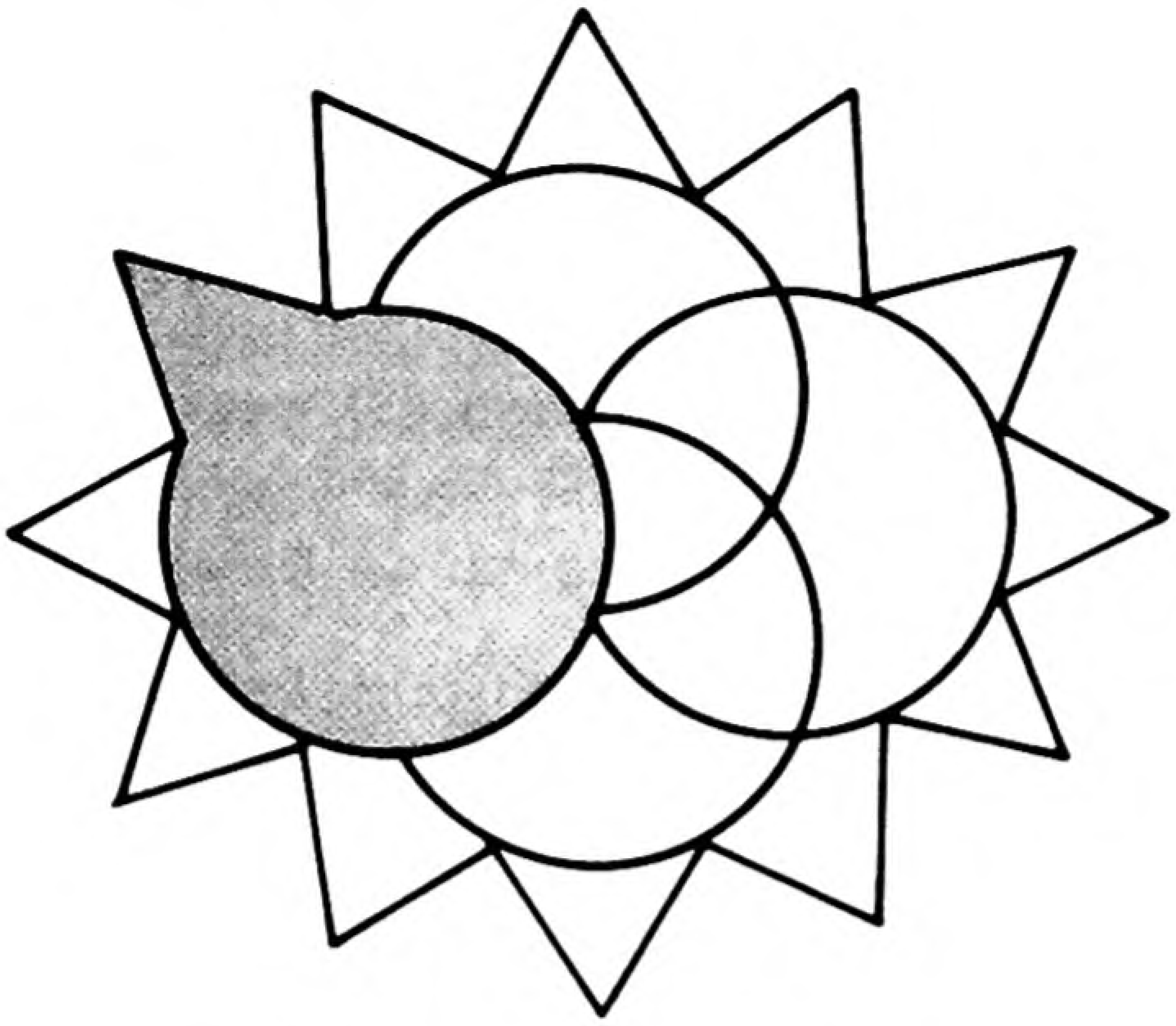
Looking ahead to the 1980s, it is logical to expect technological innovations to alter the mechanical aspects of monitoring. New instruments will be devised to measure physical properties that have not been evaluated previously and the properties now being evaluated will be measured more precisely. It is only a small step further to connect these sophisticated devices to production machinery for an automatic control system that inspects, accepts or rejects, and continuously adjusts the machinery according to feedback data.

Along with completely automatic factories for mass production, there still will be conventional plants producing a huge variety of new and old products. New products are highly susceptible to quality problems during early stages of production. Older products often rely on a reputation that was earned by consistent attention to quality craftsmanship. In both cases the quest for quality will include the use of traditional statistical controls and programs to increase everyone's involvement. Thus the quest will continue, probably at an accelerating pace.

## REFERENCE

1. Two government documents on sampling have become accepted standards for industrial use: Military Standard MIL-STD-105D, *Sampling Procedures and Tables for Inspection of Attributes*, April 1963; and Military Standard MIL-STD-414, *Sampling Procedures and Tables for Inspection by Variables for Per Cent Defective,* June 1957. Both are available from the Superintendent of Documents, Washington, D.C.

# Chapter 13



# Deciding

**KEY SUBJECTS**

*There is no way for a manager to escape demands for decisions.* Although specific decision situations vary widely, they have four consistent characteristics:

1. Alternative courses of action are available.
2. Outcomes of the alternatives can be evaluated.
3. The likelihood of outcomes can be estimated.
4. Objectives to guide the choice among alternatives are known.

*Obtaining dimensions for all the factors involved in decision making is difficult but possible. Ranking* is the simplest but least useful method of rating *intangible* qualities. The use of pairwise comparisons of qualities can improve the consistency of the rankings, but the resulting *ordinal* scale still cannot be manipulated by ordinary arithmetic operations.

*Interval* scale ratings require more effort to develop than rankings, and they provide more information. An interval scale, as in temperature scales for thermometers, does not have a natural zero. Therefore, it is necessary to establish a unique scale for each quality to be measured. One method of developing this scale is to compare mentally the quality of various decision outcomes with the best and worst possible outcomes. By this method you locate intangible characteristics on a scale from 0.0 to 1.0 according to their relative significance. Then you use the ratings to aid in the evaluation of the preferred alternative.

A tabular approach which allows the inclusion of both familiar and intangible ratings has four steps: (1) selection of independent criteria to judge alternatives, (2) rating of the relative importance of criteria, (3) assigning values to the extent alternatives satisfy criteria, and (4) calculations and comparisons of total scores for alternatives.

*Decisions recognizing risk occur when an outcome has different values for different future conditions.* To analyze a problem under conditions of risk it is necessary to be able to identify all possible future states, estimate the likelihood of each state, and determine the value of the outcome assuming each state does occur. With this information you can construct a *payoff table*. The *expected value* of each alternative is the sum of outcomes multiplied by their respective probability of occurrence. You give preference to the alternative with the greatest payoff.

*When decisions involve states of nature in which the outcomes are known but their likelihood of occurrence cannot be determined, several principles are available to assist the decision seeker.* If the decision is based on a competitive environment, *game theory* is appropriate. In the more numerous situations where no obvious opponent is influencing future states, criteria such as equal-likelihood, maximin, partial-optimist, and regret can be employed. The decision maker has to select the criterion that best matches his personal feelings.

No single decision rule has unanimous support from practitioners or theorists. The selection of specific decision tools depends on individual choice, management policy, and the resources available to assist the decision process.

## DECISION MAKING

*What do you want done? When does it have to be completed? How much can be spent? Where do we get it? Who should do it? Will you arrange it? Can I count on you?*

Such questions form a steady background refrain for management activities. Each question begs an answer, and each answer requires some kind of decision. Most are trivial; just routine responses to routine questions that have been asked before. Frequently the questions are familiar but different asking conditions cause different answers. A few are apparently important, at least they seem so until diagnosed. Sometime later all the decisions blend into an obscure pattern to be recalled with pleasure, embarrassment, grief, or pride. The purpose of studying decision making is to improve the pattern.

There is really no way to escape demands for decisions without becoming a vegetable. Every pivotal point in life demands a decision. It has been so since men chose between throwing rocks at hungry animals or running away. We are still choosing and always will be; perhaps we are even getting better at it.

We have to get better just to stay even. Early man had a simple choice: fight or flight. He did not have to select a weapon because he had nothing but rocks in his arsenal. His foe was simply an appetite on legs, not noted for its guile. Today's encounters are much more complicated. Distractions and complexities surround managerial decision makers. There are abundant resources to consider and many outcomes to evaluate. As represented in Figure 13-1, personal factors intermix with business factors to create a bewildering array of things to think about.

With all the complexities complicating significant decisions, no one should expect to be right every time. But we should learn something from both our correct and incorrect decisions. We can also learn from the mistakes and successes of other decision makers. The following examples describe decision situations that did not lead to the results originally expected, yet each provides an enlightening lesson to guide future decision making.

Case 1: A few years ago one of the "big three" automobile manufacturers decided car buyers wanted a classy new entry in the medium-size, middle-price range. The "want" was probably accurate when the opinions were collected, but it took over two years to produce the first "wanted" model. In the interim period between data compilation and car production, buying preferences switched to low-cost compacts. The decision produced the right car at the wrong time.

**Lesson: You need current data to make current decisions.**

Case 2: A major food-processing company wanted to break into the baby food market. They chose a clever approach by attempting to capitalize on the growing popularity of frozen foods. The result was a line of frozen baby foods. Before introducing the line, taste trials were conducted; parents were impressed and babies apparently were satisfied. Packaging, price, and many other factors

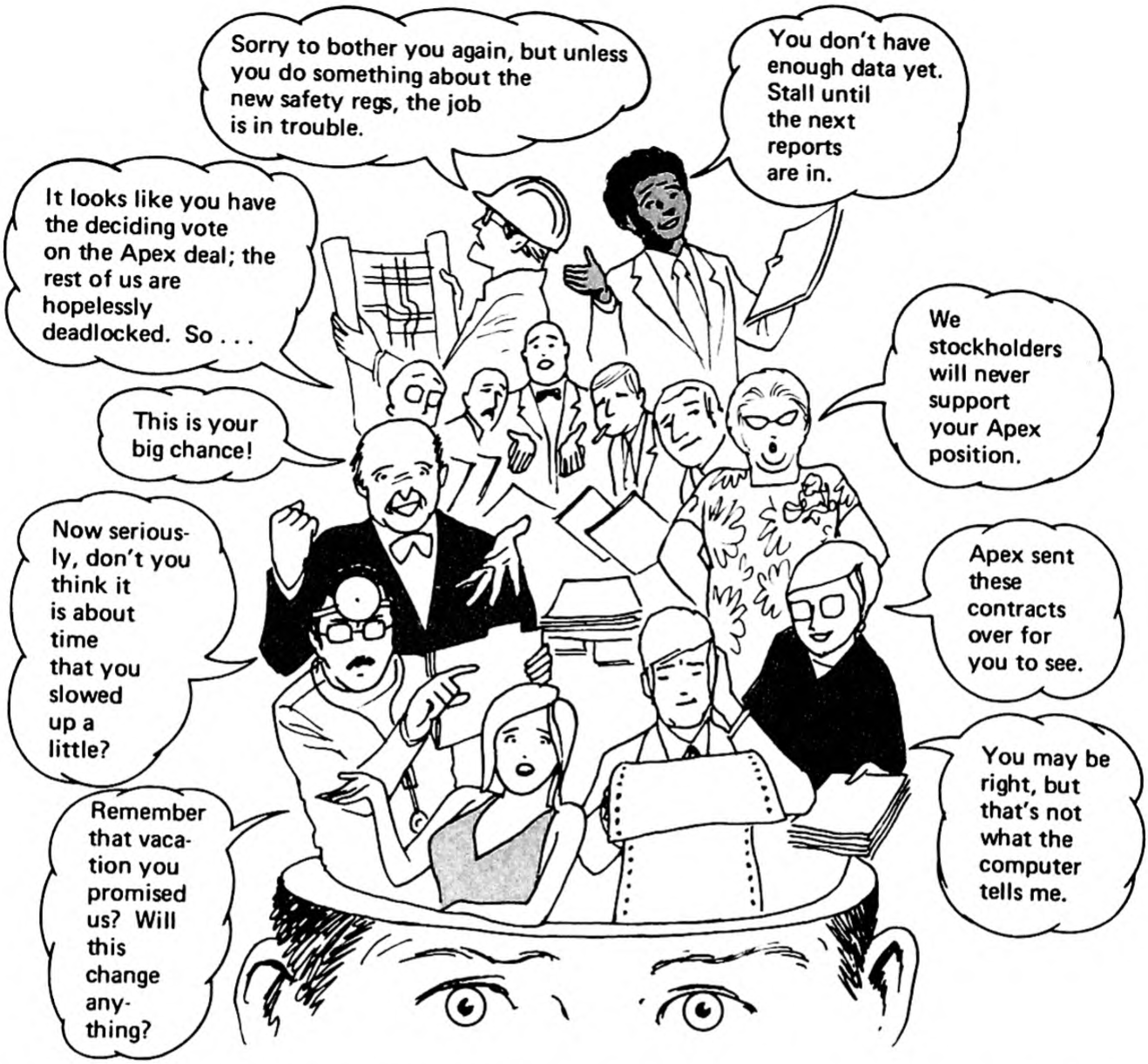

Sorry to bother you again, but unless you do something about the new safety regs, the job is in trouble.
You don't have enough data yet. Stall until the next reports are in.
It looks like you have the deciding vote on the Apex deal; the rest of us are hopelessly deadlocked. So . . .
This is your big chance!
We stockholders will never support your Apex position.
Now seriously, don't you think it is about time that you slowed up a little?
Apex sent these contracts over for you to see.
You may be right, but that's not what the computer tells me.
Remember that vacation you promised us? Will this change anything?

*Fig. 13-1. Every significant management decision is influenced by inputs from many sources. Most of them are closely related to the main question but some, often personal, have no obvious relationship yet are still influential. Effective decision making utilizes both the science and the art of management.*

were tested and found adequate. One factor did not get enough attention: buyer habits. It turned out that baby food buyers continued to go to the established baby food section of the supermarkets to look for familiar brands; they apparently were unwilling to search in the frozen food section for an unfamiliar product. The decision produced the right food at the wrong place.

**Lesson: You have to have complete data before you get a complete picture.**

Case 3: A manufacturer decided he could cut packaging costs by replacing his manual packing and boxing operation with an automatic machine using plastic sheets. The objective appeared securely identified as cost reduction. But the firm was cautious.

Before plunging into the details of design, the firm checked with customers as to their acceptance of plastic packaging. They agreed the new package was as good as the old, but closer checking disclosed a completely unexpected sequel. The users did not want individual packaging. They considered the uncrating a waste of time. Accordingly, the objective changed from economy to service, a subtle shift toward the longer-range profit motive. Racks with reusable covers replaced the crating. The customers were happier than before and the manufacturer still showed a saving, his original strategic objective.

**Lesson: The search for a better solution may identify a different problem.**

Case 4: A playing-card printer received occasional complaints about cards missing from a new deck. Since the complaints were violent (nothing is more useless than an incomplete deck of cards), the printer finally thought of marking each deck with a code indicating the origin: a tiny number and letter stamped on the joker would reveal the guilty production source when a deficient deck was returned.

An explosion of mail followed this unfortunate choice of decision alternatives. Typical letters ran somewhat along the following lines: "I bought your deck 4K. Where is my prize?" "Is 5T a winner in your new contest?" "Enclosed is joker 1B from a deck missing the three of spades. Does this mean anything?"

**Lesson: A decision that solves one problem may create new problems.**

The catalog of obstacles to sound and satisfying decision making could stretch on almost indefinitely. But regardless of the barriers, we still have to make decisions every day. You might say we are engaged in decisionship.

When we admire a person's character, we are paying tribute to his decisionship. He has a history of wise choices. The sum effect of consistently astute decisions produces a respected image. This position comes naturally to a few; most must earn it. Mental earning means learning.

A wealth of advice for making better decisions has been accumulated. Some of it dates back to well-worn proverbs of ancient seers. The modern emphasis is on the use of numbers. Decisionship incorporates the elements of both the old and new, both the qualitative and quantitative, both the art and science of management.

## DECISION CHARACTERISTICS

Although specific conditions for a decision cover the spectrum of possibilities, four general characteristics are noteworthy:

1. Alternative courses of action are available.
2. Outcomes of the alternatives can be evaluated.
3. The likelihood of outcomes can be estimated.
4. An objective to guide the choice among alternatives is known.

Each of these characteristics will be discussed in the following sections with reference to what we have observed in previous chapters.

### Alternative Courses of Action

At least a pair of alternatives must be present for a decision situation to exist. When there is a question or a problem with a single answer, no choice is possible. However, the apparent lack of alternatives may actually represent a lack of information about the situation. In effect, an alternative does not exist if the decision maker is not aware of it while deciding. In Chapter 2 we looked at ways to search for more information and the role of creativity in seeking alternatives.

The influence of the organizational structure in which a decision maker operates was suggested in Chapter 3. A manager can be isolated from the full scope of a decision by a well-meaning staff. He may be informed of only two or three alternatives because his staff has already screened out other possibilities they thought were less attractive. This condition can exist at most links in the chain of command, since subordinate levels filter out what they feel is not worth transmitting upward. Individual decision makers may also limit the range of alternatives by personal conceptions of what is reasonable to consider. Meagerness in the menu of identified alternatives cannot be compensated for by thoroughness in subsequent evaluations.

### Outcomes of Alternatives

Any course of action is logically expected to produce some kind of outcome. Two difficulties confront the decision maker in evaluating these results:

(1) a single alternative frequently has several outcomes and (2) each outcome must be rated with respect to the decision objectives. Consider the outcomes involved in deciding how to reduce losses from shoplifting in a retail store. One alternative is to hire a security guard. The surest result of this course of action is that another person will be added to the payroll. The hoped-for outcome is that thefts will decrease. But other aspects of having a guard are not so apparent. Would customers feel uncomfortable in the guard's presence? Would an arrest disrupt store operations? Could the guard be helpful in other areas such as answering questions? A list of outcomes establishes the criteria by which all competing alternatives are eventually evaluated.

To make the evaluations you have to rate each outcome of each alternative. Most ratings take the form of monetary values. In our example of the security guard, the cost of employing the guard and the savings expected from his work are naturally expressed in dollars. The sources and use of such financial data were discussed in Chapters 4 and 7. Less tangible outcomes such as the cost of uncomfortable customers and the benefit of information provided by the guard are not readily expressed by financial figures. Yet these criteria affect the decision and deserve inclusion in the evaluation. Suggestions for handling intangible considerations are offered later in this chapter.

### Likelihood of Outcomes

Since outcomes always occur in the future, it is not unusual to know only the range of values for an outcome, without knowing the specific amount. For example, a new book might be expected to sell somewhere between 10,000 and 30,000 copies in its first year, but it would be presumptuous to pick an exact level of sales. After it is admitted that a range of values is the most realistic expression of an outcome, the next step is to divide the range into increments and to estimate the likelihood of each increment. For instance, book sales could be divided into increments of 10,000 with the following statements of likelihood:

| SALES | PROBABILITY | STATEMENT OF LIKELIHOOD |
|---|---|---|
| Under 10,000 | 0.00 | No less than 10,000 copies will be sold |
| 10,000 to 20,000 | 0.65 | The probability of selling between 10,000 and 20,000 copies is 0.65 |
| 20,001 to 30,000 | 0.30 | A 30% chance of selling more than 20,000 but no more than 30,000 copies |
| Over 30,000 | 0.05 | There are only 5 chances in 100 that sales will exceed 30,000 copies |

We encountered probability statements in Chapter 12 in our discussion of quality control charts and acceptance sampling. Earlier in the text we treated all outcomes as being certain to occur. For most situations this assumption of certainty is sensible because the outcomes are due in the immediate future and there is strong historical evidence to support a particular value. The assumption of a single known outcome for each criterion allows us to use the investment comparison methods of Chapter 4, the scheduling techniques in Chapters 6 and 11, and the allocating methods of Chapter 8 to optimize the use of resources. By assuming certainty we simplify the mathematical analysis of alternatives and still obtain reasonably accurate evaluations. While realizing that few things are absolutely certain to occur, we should also be aware that assuming a specific range of values is similarly venturesome.

When it is appropriate to evaluate a range of values for an outcome, there are special mathematical and logic models to assist decision making. We will explore two conditions in this chapter, one for situations where a probability can be estimated for each value in the range, and another for the condition where the values are known but probabilities cannot be legitimately assessed.

### Decision Objectives

It goes without saying that decision making is an exercise in futility if it serves no objective. That is why it is so easy to make a decision for someone else. When the decision maker is not personally a winner or a sufferer from an outcome, he can make a superficial choice. The opposite extreme occurs when a decision maker is so immersed in a situation that he attempts to make every decision satisfy multiple objectives. As long as there is no conflict among the objectives, he may succeed but he will surely tax his stamina and patience.

Defining an objective molds the criteria for evaluating outcomes. An executive might have first-year objectives for a new product to net $1 million and to capture 30 percent of the market. These objectives are both easily measured and nonconflicting. An additional objective for the new product not to compete with existing company products in the same market would be difficult to measure and could possibly conflict with the other objectives. A question also arises as to the strictness of objectives. Would an expected outcome of a $950,000 profit really exclude an alternative from further consideration when the objective was to net $1 million?

The selection of decision objectives ties together all phases of the decision process. Objectives guide the choice of alternatives, set the criteria for evaluating outcomes, and indicate what degree of certainty can be assumed while deciding.

You have to decide what future state you want to achieve before you decide what to do now to achieve it.

## DIMENSIONS FOR DECISIONS

Dimensions are one of the stickiest problems in decision making. Many factors that affect decisions have no natural measures. Yet we need some kind of numbering system to rate the relative importance of these factors.

Difficult to measure characteristics are often called *intangibles*. The only easy evaluation involving intangibles occurs when just two alternatives are compared for a single criterion. Then it is merely a matter of judging which alternative is more satisfying. For instance, in choosing between two prints of a photograph, you might prefer one because it creates a better impression. There are no established scales by which to rate impressions; they are intangible.

### Ranking

Simple ordering, as in the choice between prints, is a very crude form of measurement. While ranking gives the nod to one alternative over another, it does not measure the amount of preference. This lack of definition is not serious for the two-choice, one-intangible case, but it leads to confusion when the question gets more complex.

We could have assigned values of 1 and 0 to the photo prints with no lessening or improvement of the comparison. However, if another print was included, a 1, 2, 3 ranking would give more information than a single choice. Assuming the three prints are labeled X, Y, and Z with respective ranks of 1, 2, and 3, the ranker expresses his preference of X over Y and Y over Z. But there is still no clue as to how much X is preferred to Y and Z, or why it is preferred.

Personnel-rating forms usually ask a rater to assign a number or to pick a proficiency level. Descriptions of performance levels are often provided to ease the chore. The satirical appraisal form in Figure 13-2 is an innocent ranking example. More serious versions are widely used in industry and government. When you pick a caption, you get a number. These numbers are then a measure of stature for the person being ranked. The ranked, ranker, and especially the reviewer should be aware of what has taken place.

Rankings must be consistent. If X is preferred to Y and Y is preferred to Z, then it is automatically assumed that X is preferred to Z. If this seems too obvious to

EMPLOYEE APPRAISAL GUIDE

| RANKING | PHENOMENAL 4 | MARVELOUS 3 | GOOD 2 | NOT SO GOOD 1 | PATHETIC 0 |
|---|---|---|---|---|---|
| Competitiveness | Slays giants | Holds his own against giants | Holds his own against equals | Runs from midgets | Gets caught by midgets |
| Personal appearance | Could be a professional model | Could model but wouldn't be paid much | Could model as the "before" | Goes unnoticed in a crowd | Panics a crowd if noticed |
| Leadership | Walks on water consistently | Walks on water in emergencies | Wades through water | Gets caught in hot water | Passes water in emergencies |
| Intelligence | Knows everything | Knows a lot | Knows enough | Knows nothing | Forgets what he never knew |
| Communication | Talks to big shots | Talks to little shots | Talks to himself | Argues with himself | Loses those arguments |

*Fig. 13-2. A spoof of an employee-ranking system that makes just enough sense to be frightening.*

be a problem, try ranking your three favorite sports. For the sake of argument, say the ranking came out skiing, golf, and jogging, in that order. Then you think again. Skiing is more thrilling than golf and golf is more fun than jogging, but jogging is healthier, handier, and cheaper than skiing. Now what ranks where?

The exit from such circular reasoning is found in more precise objectives. The intangible values of sports could be ranked according to fun per minute of activity, amount of exercise per outing, fellowship enjoyed, satisfaction obtained, etc. Each of these qualities could be the basis for a different ranking episode. They cannot be mixed effectively within one rank. Only one dimension is implicit in a ranking episode. Each criterion deserves it own trial.

### Ordinal Scale Comparisons

After narrowing the purpose of ranking to a single merit such as smaller than, higher than, sweeter than, heavier than, etc., all methods of ordering are about the same. Each item in a *simple ordinal scale* ranks above or below every other item. Whether you start with a "most preferred" level and order downward or reverse the process to work from the bottom up, the ranking is essentially by pairs.

One way to make rankings more methodical is to use listed pairings. Assume there are five alternatives to be ranked for the same criterion: V, W, X, Y, and Z. As shown in Figure 13-3, all possible pairings are listed on the "steps." There

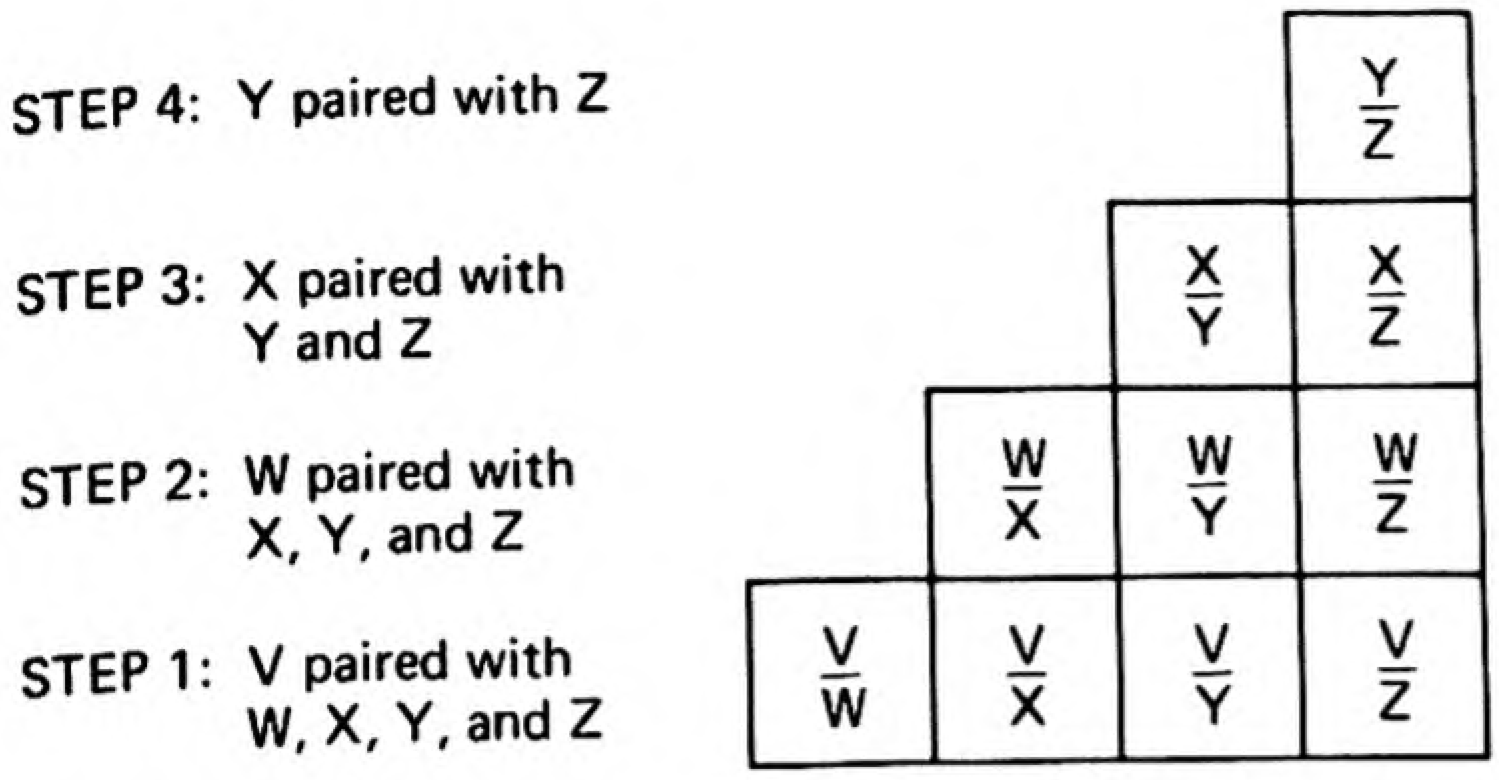

STEP 4: Y paired with Z
STEP 3: X paired with Y and Z
STEP 2: W paired with X, Y, and Z
STEP 1: V paired with W, X, Y, and Z
Y/Z
X/Y
X/Z
W/X
W/Y
W/Z
V/W
V/X
V/Y
V/Z

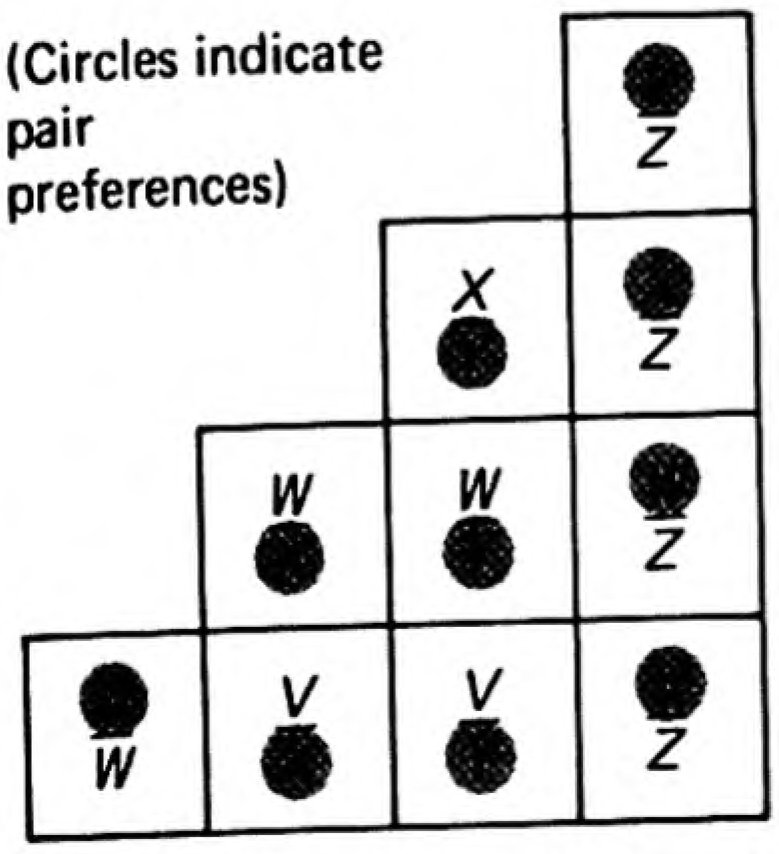
*Fig. 13-3. Step-by-step comparison of alternatives* V, W, X, Y, *and* Z.

will always be one step less than the number of items to be compared. The sequence in which the items are listed is purely arbitrary.

In the first step, V is paired with W, X, Y, and Z. In the second step V is dropped and the next item, W, is compared in turn to the remaining items. The procedure is continued until a single pair remains.

Ranking is accomplished by circling the preferred item in each comparison. In the first step, if V is preferred to W and Z, it is circled for these pairs. Meanwhile, X and Y are circled to show their rank above V. Similar comparisons are made for each step with the results recorded by three circles in step 2, two circles in step 3, and a single circle in step 4.

A formal ranking follows from a tabulation of the number of times each item is preferred. In the example continued in Figure 13-4, item Y was circled four times to receive the top rank. Z was never preferred and consequently ranks last. The number of votes (circles) is equal to half the product of the number of steps times the number of items; for our example there are ½ × 4 × 5 = 10 circles.


(Circles indicate pair preferences)
Y
Z
X
Y
X
Z
W
X
W
Y
W
Z
V
W
V
X
V
Y
V
Z

| ALTERNATIVE | NUMBER OF CIRCLES | RANK |
|---|---|---|
| V | 2 | 3 |
| W | 1 | 4 |
| X | 3 | 2 |
| Y | 4 | 1 |
| Z | 0 | 5 |

*Fig. 13-4. With circles showing the preference among pairs at each step, the final tabulation indicates that the ordinal scale for the five alternatives is Y over X over V over W over Z.*

Now that we have numbers to represent impressions, we have the tools to be dangerous. The 1, 2, 3, 4, 5 ranking may suggest the top priority item, Y, is five times as impressive as the lowest rank, Z. It may imply that the difference in preference between Y and X and V and W and Z are equal. Neither proposal is correct. Rankings *cannot* be manipulated by ordinary arithmetic operations. They cannot be added, subtracted, multiplied, or divided to produce meaningful results. As far as usefulness goes they are the least valuable type of measurement, but they may also be the only legitimate type for intangibles. Because they are fragile, they need special handling.

## UTILITY OF OUTCOMES

Significant decisions involving several intangible qualities require more than a simple order of preference for a dependable solution. As proof, consider the problem of choosing which university to attend when the criteria used in the choice are reputation and cost. If we assume both criteria are of equal importance, the rankings below could result from the comparison.

| ALTERNATIVES | REPUTATION | COST |
|---|---|---|
| Multiversity Center | 1 | 3 |
| Hometown College | 2 | 2 |
| Ivy Clad University | 3 | 1 |

Which is the preferred university?

Because rankings do not reveal the degree of preference, no decision is apparent, and a more refined scaling method is needed.

About the best measurement of intangibles we can strive for is an *interval* rating. This type of scale provides a relative measure of preference in the same way a thermometer measures relative warmth. An interval scale is a big improvement over ranking, but it still cannot be used like a ratio scale of distance or weight. This limitation stems from the lack of a natural zero. A zero in a ratio scale has a universal meaning; a zero distance or a zero weight means the same thing to everyone. A zero temperature can convey different meanings according to the type of interval scaling employed: Fahrenheit or centigrade. But once this zero value is understood, both temperature scales use standardized units of measurements which allow certain arithmetic operations, such as averaging, to be performed with the scaled values.

To develop an interval scale for intangibles we can adopt a scale range that stretches from zero to one, from least satisfying to most satisfying. Again using the example of choosing which college to attend, we recognize that "reputation" is the criterion which lacks natural dimensions. In order to establish the extreme points of our scale, we try to visualize a university with the greatest reputation we can comprehend. This university gets a 1.0 rating, the top value. Then we imagine a university with the lowest reputation that would still be considered as a possible choice. This school is given a 0.0 rating.

All the universities we wish to compare will now fit on the scale defined by the two end-point descriptions. Next we attempt to find the relative position of each alternative (university to attend) on this scale. We do so by setting up a theoretical lottery that matches our preference for the top rated university (1.0) over the lowest rated (0.0) against attending one of the alternative universities for sure. A specific lottery to obtain a rating for Ivy Clad University would result from answering the question, "What is the probability I would accept going to the 1.0 rated school instead of the 0.0 school rather than attending Ivy Clad U. for sure?" Suppose you answered 0.40. That would indicate attending Ivy Clad is as attractive as a wager that gives 4 chances in 10 of attending the top university, or, equivalently, a wager that gives 6 chances in 10 of being forced to accept a very low rated university. This 0.40 probability is the rating on the interval scale for Ivy Clad University.

The process of setting up mental lotteries is repeated for all alternatives to be rated. If the rating selected for Multiversity was 0.90, it would indicate that the certain opportunity to attend Multiversity was considered equivalent to taking a chance that 9 times in 10 would allow attendance at the university with the highest reputation. A 0.5 rating for Hometown College shows no preference between it and a 50/50 chance of going either to a very high or to a very low reputation school. The relative positions of the three alternatives derived from the described lotteries are shown on the graph in Figure 13-5.

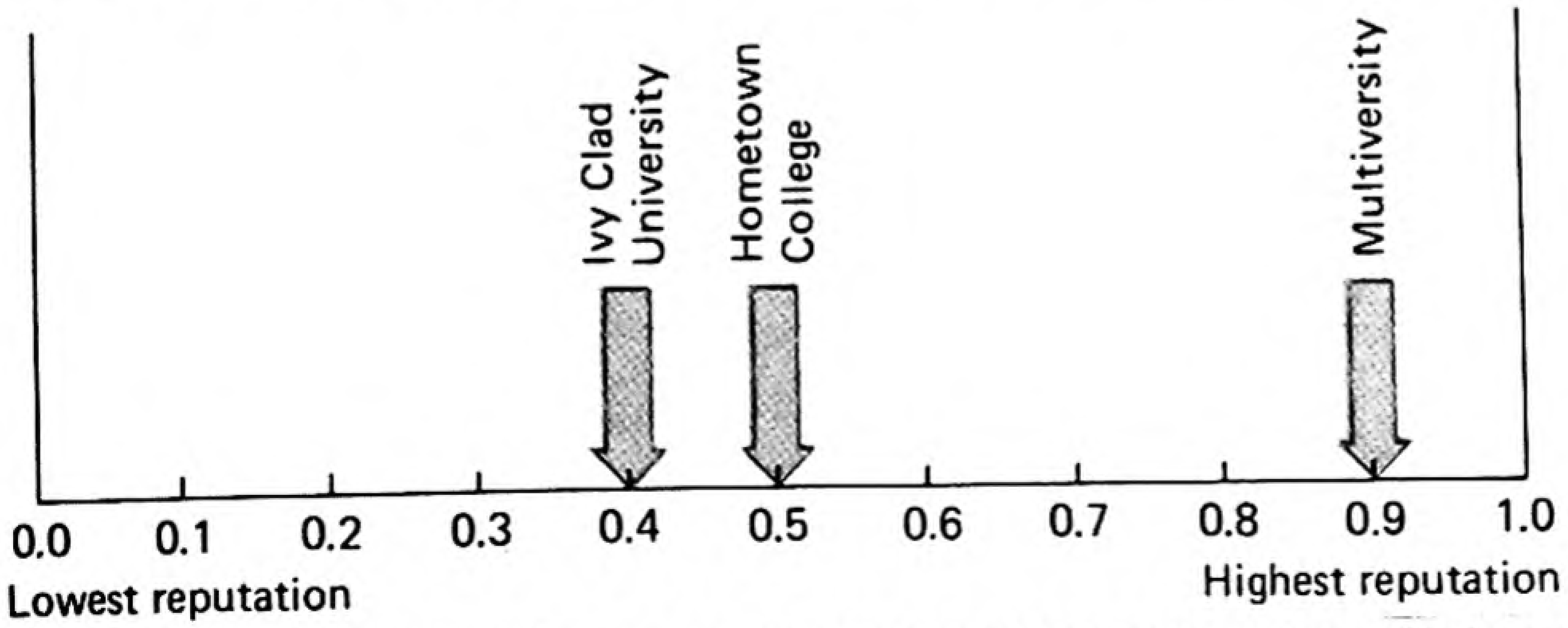


*Fig. 13-5. Interval scale assignments for three alternatives. Ratings represent the preference for each school based on the "intangible" criterion.*

Such hypothetical gambling is a demanding intellectual exercise. It is difficult to retain the image of conditions at the top and bottom of the scale. Weighing probabilities to balance the lottery is also a tough task. It would, of course, be much easier to do the gambling with familiar measurements. For example, if the two ends of the scale were $1000 and zero dollars, it would not be too demanding to pick a cash value that you would be willing to accept for sure (the alternative) in place of a 50/50 chance to win $1000 or nothing. A choice of, say, $400 for the alternative means the rater is indifferent to a sure gain of $400 and to taking a chance on the flip of a coin (0.50 probability) to get $1000 or nothing. In this example it is simple to visualize the gains and losses because we are accustomed to monetary values; unfortunately we are not so well prepared to visualize ratings for reputation, beauty, and other intangibles that enter into many decisions.

There are additional reasons for caution. Feelings, whether committed to numbers or held in limbo, are subject to dramatic change. Few people are consistent. A temptation to gamble against odds on one occasion is replaced by extreme pessimism on another occasion that is outwardly identical to the first.

Another danger is misunderstanding probabilities. A catastrophic loss, the alternative with the 0.0 rating, even though it has almost no chance of happening, may have such a strong impact that it distorts the whole utility scale. Preoccupation with disaster tends to crowd conservative alternatives far up the scale from alternatives even remotely connected to catastrophe. A similar affliction is the awe or suspicion we feel for certain numbers owing to previous personal experiences.

To get closer to the problem, consider a gent who nearly faints at the thought of drowning. He has to go to Europe and is rating the "safety" of air versus sea transportation. The rating scale stretches from a 0.0 rating for death to a 1.0 for a healthy arrival. Suppose he believes the chance of a fatal accident via sea is 1 per million and via air is 1 per 100,000. He also knows that the 1 in a million accident will most likely be by drowning. So, with odds of 10 to 1 in favor of a safer trip by sea, he chooses to fly. He cannot see the obvious because of emotions. As trees hide forests, fears foul facts.

## MIXING, DISTILLING, AND DECIDING

The mental rendering involved in converting feelings to numbers helps avoid untidy reasoning and may even signal an obvious solution. It can also confuse issues. When the inputs to a decision are easy, familiar terms, such as dollars or inches or ounces, the average decision seeker knows how to handle them. He tries to earn dollars or conserve inches or save ounces. He might have trouble resolving clashes such as having to spend dollars to save minutes, but he is accustomed to this type of conflict. He accepts the trade-off between dollars and minutes. He is far less likely to accept a trade-off between dollars and reputation or minutes and safety.

Two major difficulties are present. One difficulty is how to include criteria with different dimensions in a single rating. Returning to the problem of selecting a university to attend, assume you have settled on a reputation rating for each institution. Say also you want to include the tuition costs and distance from your home as criteria in the evaluation. Now we have three different dimensions to consider: utility scale for reputation, dollars for tuition, and miles for distance. These mixed dimensions must be distilled into a one-number rating for each university alternative.

The four steps listed below provide a procedure for combining different outcome dimensions into a single number that represents each alternative.

1. Select independent criteria by which to compare all alternatives.
2. Rate the relative importance of the criteria.
3. Assign values to the extent each alternative satisfies each criterion.
4. Calculate and compare scores for all alternatives.

There are several ways to conduct the suggested procedures. In the following paragraphs we will examine one popular method:

**STEP 1:** Use techniques described previously to develop a list of criteria that influence the question to be decided. Separate necessities from desirables. Keep in mind that a quantitative value must be developed to measure how well each criterion is satisfied.

> As a sample application of the steps, consider the career question confronting a junior executive (his self-proposed title) who is about to leave business school with a fresh diploma. He confidently expects to be wooed by generous recruiters and consequently erects the following list of expectations:

Necessary: 1. Adequate salary ($15,000 a year, minimum)
2. Location (must be in U.S.)
Wanted: 3. Advancement opportunities
4. Congenial associates
5. Fringe benefits
6. Technological exposure

**STEP 2:** Use ranking or utility-rating procedures to determine the relative importance of each criterion. For convenience, use a scale of 1 to 10 (each increment of the utility scale is multiplied by 10) with higher numbers indicating a greater importance.

> The aspiring manager places high value on immediate comforts as indicated by his shopping list priorities:

| | CRITERION | IMPORTANCE |
|---|---|---|
| 1. | Salary | 10 |
| 2. | Location | 10 |
| 3. | Advancement | 7 |
| 4. | Associates | 8 |
| 5. | Benefits | 5 |
| 6. | Technology | 3 |

**STEP 3:** Identify the various outcomes. To increase consistency, rate all alternatives for one criterion before going to the next criterion. Convert the criteria ratings to a 1 to 10 scale. Number 10 denotes the most attractive outcome.

> Our job-seeker's possible futures are narrowed to three alternatives by the lack of offers from more companies. He evaluates each offer by translating the obvious outcome measurements to the 1 to 10 scale. Then he rates subjectively the other factors according to the degree they meet his expectations, as defined by the list of wanted characteristics.

| CRITERION | CHARACTERISTICS |
|---|---|
| 1. Salary | A high starting wage is a conspicuous want so all offers are compared to the best offer and translated to the 1 to 10 scale by using the following ratio: $\frac{\text{salary offer from given company}}{\text{highest offer by any company}} \times 10$ |
| 2. Location | Minimum distance from hometown is desired. The mileage ratio for the 1 to 10 scale conversion is then $\frac{\text{distance to job closest to hometown}}{\text{distance to given job from hometown}} \times 10$ |
| 3. Advancement | Rating is based on forecasts of growth for the given company, review of past and present promotion policies, and a survey of immediate peer competitors. |

| | | |
|---|---|---|
| 4. | Associates | Observations are made of company morale, quality of peer- and upper-level management, and shared interests of potential associates. |
| 5. | Benefits | Equivalent dollar values are calculated for vacation time, paid insurance, profit sharing, bonuses, retirement plans, and similar values. The total values are then equalized according to a cost of living factor and put into the ratio below:<br>$\frac{\text{benefits for given company}}{\text{highest benefits from any company}} \times 10$ |
| 6. | Technology | Rating is based on how much professional growth will accrue from association with the company during a five-year period. |

A consistent planning horizon such as five years should be used in considering all characteristics. Note also that factors to be minimized (the distance criterion) or maximized (the salary criterion) can be expressed on the same 1 to 10 scale by using appropriate ratios.

**STEP 4:** When an alternative fails to meet a "necessary" cutoff level for a criterion, eliminate it from further contention. For all the remaining alternatives, multiply each criterion rating by its respective importance number, and add the products of all multiplications. The alternative with the highest total is the preferred solution.

The tally sheet shown in Figure 13-6 indicates our manager-to-be should accept the offer of the Upandown Company where he can be most comfortable, while helping the firm prosper with his decision-making talents.

## DECISIONS RECOGNIZING RISK

All managers realize they cannot be absolutely certain an outcome will materialize as expected, but they make most of their decisions under this assumption of certainty. This seemingly negligent policy is actually sound. Alternatives are typically designed to produce a certain outcome, and considerable thought is devoted to make that outcome as likely as possible. There should be compelling reasons to doubt an outcome's value before you abandon the certainty assump-

| ALTERNATIVES | | INANDOUT COMPANY | | | R&D, INCORPORATED | | | UPANDOWN COMPANY | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CRITERIA | Imp. | OBSERVATIONS | Rate | RxI | OBSERVATIONS | Rate | RxI | OBSERVATIONS | Rate | RxI |
| Salary: $15,000/year minimum | 10 | pays $18,000/yr.<br>$\frac{18{,}000}{18{,}000} \times 10$ | 10 | 100 | pays $13,000/yr.<br>below minimum | | | pays $16,000/yr.<br>$\frac{\$16{,}000}{18{,}000} \times 10$ | 9 | 90 |
| Location: Must be in U.S.A. | 10 | Megopolis, N.Y.<br>distance = 500 mi.<br>$\frac{300}{500} \times 10$ | 6 | 60 | | | | Fairlake, N.C.<br>distance = 300 mi.<br>$\frac{300}{300} \times 10$ | 10 | 100 |
| Advancement | 7 | good growth<br>fast promotions<br>tough competition | 8 | 56 | | | | irregular growth, recently fast<br>not much competition | 5 | 35 |
| Associates | 8 | high enthusiasm<br>too many cliques | 6 | 48 | | | | morale high now, but fears cutbacks<br>friendly, open atmosphere | 7 | 56 |
| Benefits | 5 | accumulated net benefits = $4,000/yr.<br>$\frac{4{,}000}{6{,}000} \times 10$ | 7 | 35 | | | | accumulated net benefits = $6,000/yr.<br>$\frac{6{,}000}{6{,}000} \times 10$ | 10 | 50 |
| Technology | 3 | respected staff<br>new equipment<br>close contact with famous companies | 10 | 30 | | | | could be a leader if current plans turn out as expected | 3 | 9 |
| TOTALS | | | | 329 | | | | | | 340 |
| DECISION | REJECT INANDOUT UNLESS UPANDOWN CANCELS OFFER | | | | | | | | | |

*Fig. 13-6.* Format for tabulating criterion ratings and comparing outcomes of decision alternatives. Since higher numbers show a preference in all cases, the Upandown Company is preferred over the Inandout Company for the given criteria.

tion. Not only must these reasons be definable, they must also be quantifiable because they form the basis for evaluation methods that include consideration of risk. That is, if an outcome has more than one possible value, the conditions that cause those values have to be identifiable and the numerical ratings for each condition have to be assessed. Then we can employ mathematical analyses to help us make decisions which recognize risk.

In this section we will consider decision situations where outcomes have different values for different future states. In addition, we will assume that the probability of the occurrence of each state can be estimated. This approach is called *decision making under risk*.

### Expectation

The likelihood of a future state of nature is expressed by a probability statement. Probability estimates are derived from experiments and from experiences with similar situations. Careful definition of the boundary of each state improves your estimating accuracy. Assume you have been asked to estimate your grade on a test you have to take. You might categorize the possible results as *good, fair,* and *bad*. These divisions could satisfy the requirement that all possible scores are accounted for, but where are the lines that separate *good* from *fair* and *fair* from *bad*? You must know these limits before you can assign any responsible probabilities. Presuming test scores range from 0 to 100, more constructive states of nature might have divisions of 100 to 85, 84 to 65, and 64 to 0. When the segments have well-defined limits and cover all possible futures, more reliable probability statements are probable.

Suppose a landscaping company has been asked to bid on two jobs, but there is time to prepare only one bid. The cost of preparing a bid and the profit percentage for both jobs are equal. The contract size will be about $200,000 for job 1 and $80,000 for job 2; and the likelihood of getting each is 0.15 for job 1 and 0.40 for job 2. From these figures we can calculate the *expectation* (E) of the alternatives.

Expectation for job 1 = $200,000 x 0.15 = $30,000
Expectation for job 2 = $80,000 x 0.40 = $32,000

The expectation indicates that the bid should be prepared for job 2 if the objective of the decision is to maximize sales.

*Mathematical expectation* is the product of an outcome and its corresponding probability of occurrence. The rationale for choosing he alternative with the highest expectation is to maximize *long-term* gains. If a bid is made for job 2, the actual result will be either an $80,000 contract or no contract. But if the company is faced with a great number of decisions with the same outcomes and probabilities, the average payoff over the long run will be larger by following the expectation principle.

### Expected Value

In the bidding example, we considered only one future state—winning the bid. The other future state was losing the bid, but since the outcome for this state was zero dollars for both jobs, it did not affect the comparison. A more compact and complete version of the bid question is shown by the *payoff table* in Figure 13-7 for job 1. The table includes probabilities for *all* states of nature and associated outcomes for each alternative. It also includes a summary indicator for comparing alternatives, the "expected value" column. Expected value (EV) is the sum of the expectations and corresponds to the average value of the outcomes.

Both outcomes and expected values may be negative. A gamble on a flip of a coin that would win $10 if a head turned up or would lose $15 when a tail showed is represented in the payoff table below.

| | **HEAD**<br>**0.50** | **TAIL**<br>**0.50** | **EXPECTED VALUE** |
|---|---|---|---|
| Coin Flip Gamble | $10 | −$15 | ($10) (0.5) + (−$15) (0.5) = −$2.50 |

The gamble is obviously a poor one for the gambler. Although he will win $10 or lose $15 on each toss, his *average* per toss is a loss of $2.50, noted as a negative value in the table.

Usefulness of a payoff table and expected value comparisons is evident in a more extensive application. Suppose a manager has to decide what to do about weld defects. He knows that his production process averages one defect per 20 units and the cost created by an undetected defect is $30 per unit. He has

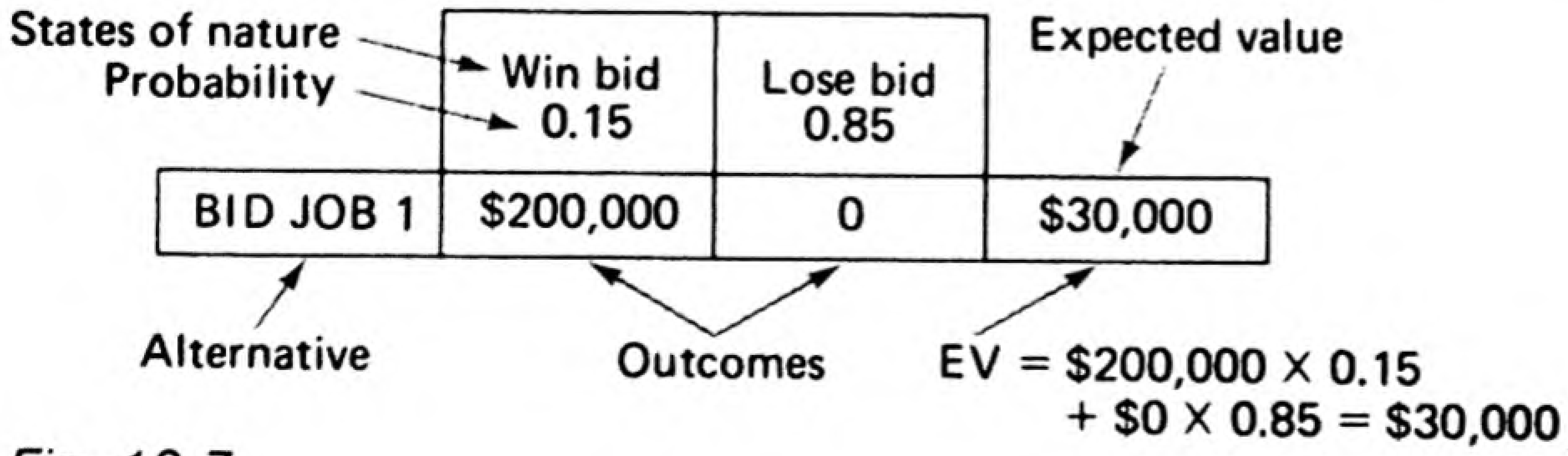


*Fig. 13-7.*

data on two detection methods: Method 1 costs \$0.50 for each inspection and locates 80 percent of the defects; method 2 costs \$2.00 per test, but it always detects a defective weld.

From these data the manager constructs a payoff table to determine the expected value of costs from each inspection method. He also includes the alternative of not doing any inspections as shown in Figure 13-8.

The states of nature are perfect and imperfect welds given as a probability of occurrence in future production. The outcome of an imperfect weld using method 1 is the loss that results from one defect in five (80 percent detection rate) going undetected plus the cost of conducting the inspections: (0.20) (\$30.00) + \$0.50 = \$6.50. Since these figures are both costs, their sum is shown as a negative number in the payoff table. In a similar fashion, the costs for method 2 are the same for both states of nature because the method allows no defects to pass undetected, and the charge is \$2.00 to test both good and bad welds. The lowest expected cost occurs for method 1, making it the preferred alternative for the cost considerations included in the decision.

The expected value principle for comparing outcomes of alternatives under conditions of risk is respected and widely used. Many adaptations have been developed to extend its application.[1] These extensions, complemented by powerful, modern data-collection and processing devices, allow deeper probes into the future to improve today's decisions.

## DECISIONS ADMITTING UNCERTAINTY

A decision maker enters a decision area beyond the one involving calculable risks when it is unrealistic for him to estimate the probability of future states of nature. If it is still possible to identify the states and to estimate the associated outcomes, there are principles to guide the comparison of alternatives.

| | DEFECTIVE WELD 0.05 | NO DEFECTS 0.95 | |
|---|---|---|---|
| METHOD 1 | −\$6.50 | −\$0.50 | −\$0.80 |
| METHOD 2 | −\$2.00 | −\$2.00 | −\$2.00 |
| NO INSPECTION | −\$30.00 | 0.0 | −\$1.50 |

*Fig. 13-8. Expected value calculations for a decision involving three alternatives and two states of nature. Preference is indicated for method 1 because it offers the lowest long-term cost.*

Which ones are used and how they are used are personal judgments the decision maker must resolve.

There are two ways to view decisions under uncertainty. One way is to consider nature as a competitor. In effect, the decision maker chooses his alternatives to minimize the gains of his opponents while trying to maximize his own gains. He assumes an equally smart and crafty opponent is doing likewise. The result is a payoff table treated like a chessboard with the rules spelled out as *game theory*. The game-theory concept of decision rules for competing players with conflicting objectives was introduced in 1947 and over the years has spawned numerous discussions. Most political campaigns, business adventures, and similar competitive situations do involve decisions influenced by how an opponent will act or react to the adoption of a course of action, but in its present state of development game theory cannot be considered a practical tool for management.

The other way to view uncertainty is to treat nature as neutral. By this assumption we say no active opposition controls the likelihood of outcomes. We admit there may be some cause and effect mechanisms that influence the probability of future states, but we cannot control them and believe no one else can either. Thus, contrary to folklore, we assume that carrying an umbrella or washing a car will not increase the probability of rain. Nature is neither willfully mean nor sympathetically kind. It is neutral.

Being able to operate in a neutral future does not relieve the responsibility to make rational decisions. We will consider several different philosophies to guide the decisions. For a given decision situation, each philosophy may suggest the selection of a different alternative. The philosophies are not arbitrary; they are based on different premises such as optimistic or pessimistic outlooks. The decision maker has to select the one that best matches his personal opinions.

One continuing example will be used to illustrate all the philosophical criteria. Assume an organization is deciding how much to expand its operations over the next several years. To simplify the considerations, we will deal with only three alternatives for the business (A1 – major expansion, A2 – limited expansion, and A3 – no expansion) and three states of nature for the general economy (N1 – prosperity, N2 – normal, and N3 – recession). The outcomes as shown in Figure 13-9 are estimated for each alternative and state of nature, but the likelihood of the economic states cannot be legitimately forecast beyond the immediate future. Different decision criteria have to be investigated for the condition of uncertainty. Each criterion is discussed in terms of maximizing gains. A goal to minimize losses would simply reverse the evaluating process.

| ALTERNATIVES | STATES OF NATURE<br>N1<br>Prosperity | <br>N2<br>Normal | <br>N3<br>Recession |
|---|---|---|---|
| A1–Major Expansion | 12 | 6 | −15 |
| A2–Limited Expansion | 6 | 3 | −3 |
| A3–No Expansion | 3 | 2 | 0 |

OUTCOME: profit per year ($100 thousands)

*Fig. 13-9. Payoff table for a decision under uncertainty involving expected profit from three alternatives and three states of nature.*

### Principle of Insufficient Reason (Laplace Criterion)

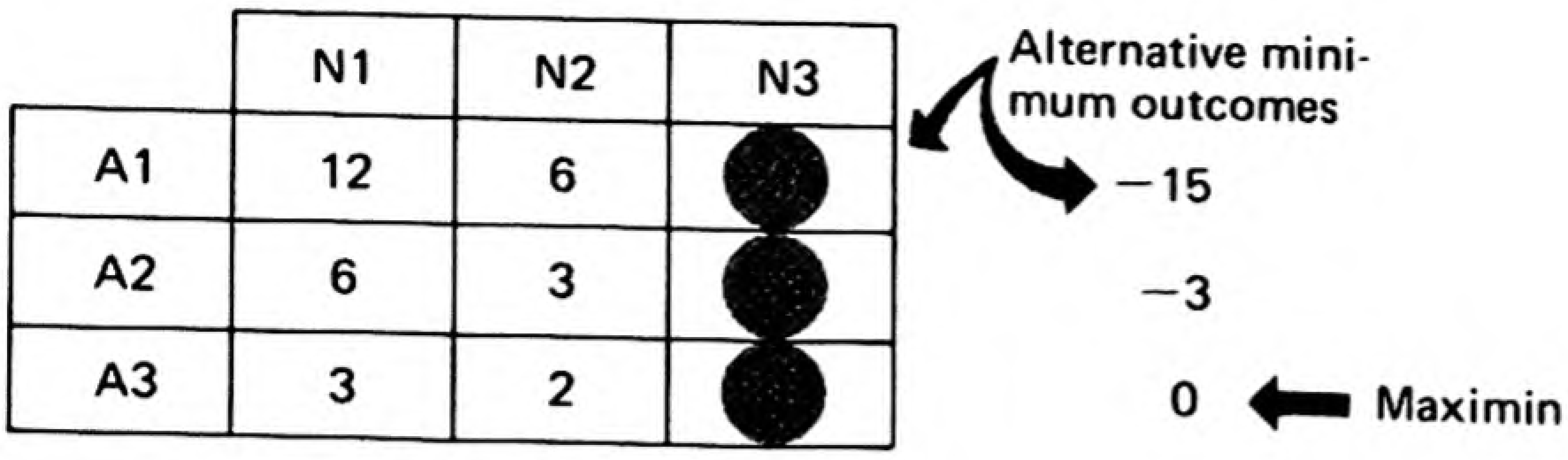
The principle of insufficient reason derives from the expected value principle employed for decisions recognizing risk. It is based on the belief that if there is no good reason to believe one state of nature is more likely to occur than any other, there is no good reason to doubt that all states are equally likely to occur. The result is that all states of nature are assigned equal probabilities whose sum is unity, 1.0. Then the expected value of each alternative is calculated using the assigned probabilities, and the alternative with the greatest indicated gain is preferred as shown in Figure 13-10.

|  | 0.33 | 0.33 | 0.33 | ⬅ Equal probabilities assigned |
|---|---|---|---|---|
|  | N1 | N2 | N3 | EV |
| A1 | 12 | 6 | −15 | •••1.00 |
| A2 | 6 | 3 | −3 | •••2.00 ⬅ Largest expected value |
| A3 | 3 | 2 | 0 | •••1.67 |

*Fig. 13-10. Selection of a preferred alternative using the principle of insufficient reason. Equal probabilities are assigned to each economic state. A preference for the A2 limited expansion alternative is indicated by calculated expected values.*

### Maximin Principle (Wald Criterion)

The word *maximin* was coined to describe the objective to *maximize the minimum possible gain.* It is drawn from an outlook that nature is essentially hostile and if an outcome can turn out bad, it will. This pessimism leads to a suggestion that the decision maker should select the alternative whose minimum outcome is the greatest among all the outcomes of all the alternatives—the maximum minimum. To make the selection, you identify the minimum number in each row of the payoff table and then choose the largest number from the group. The alternative so recognized is preferred by conservative decision seekers.



| | N1 | N2 | N3 |
|---|---|---|---|
| A1 | 12 | 6 | ● |
| A2 | 6 | 3 | ● |
| A3 | 3 | 2 | ● |

*Fig. 13-11. Alternative A3 (no expansion) is preferred according to the maximum principle because A3 assures the least loss.*

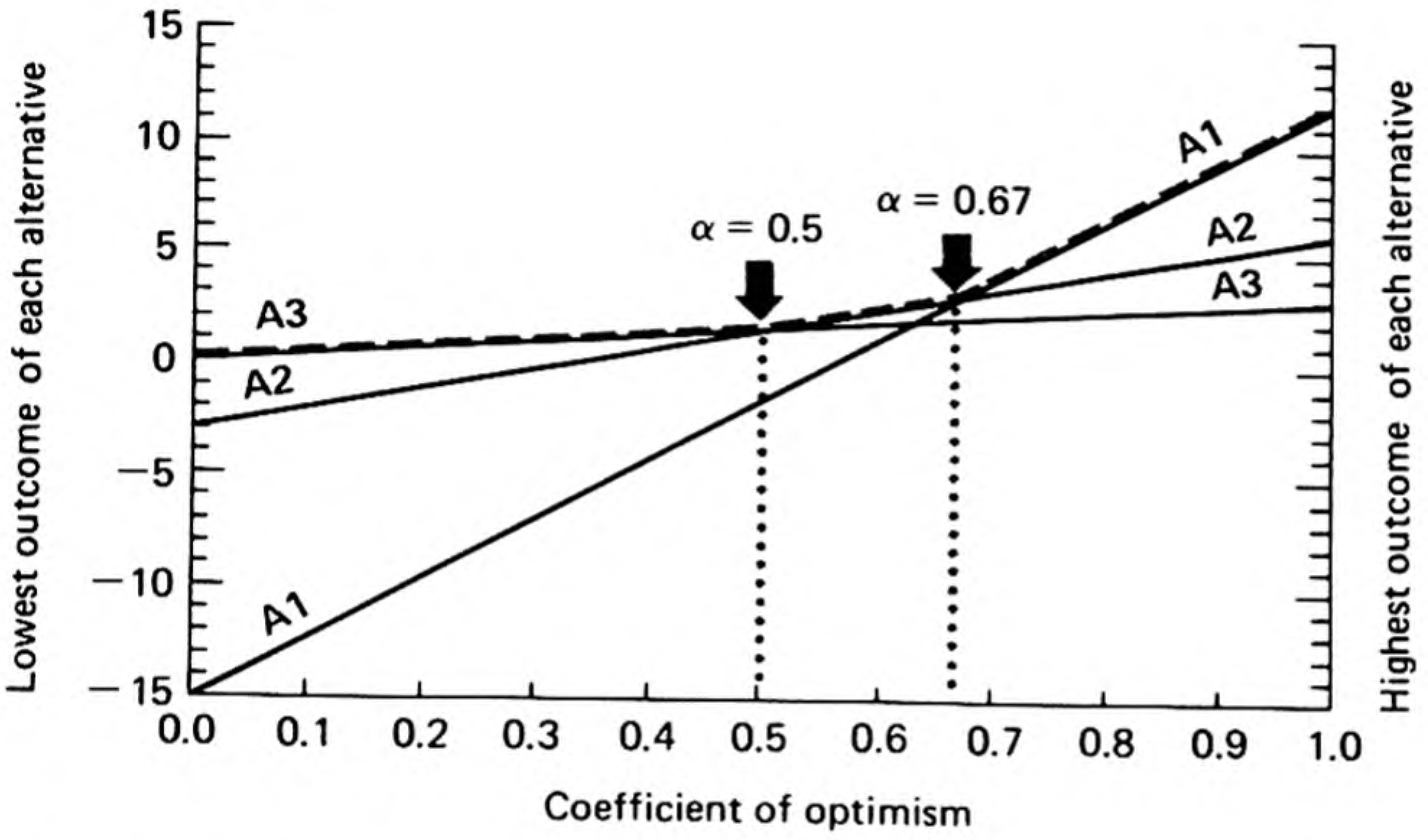


*Fig. 13-12. Preference pattern for alternatives resulting from different coefficients of optimism in the application of the partial-optimist principle. A3 is preferred for $\alpha$ values of 0.0 to 0.5, A2 from $\alpha = 0.5$ to 0.67, and A1 from $\alpha = 0.67$ to 1.0.*

### Partial-Optimist Principle (Hurwicz Criterion)

The opposite of a maximin philosophy is *maximax,* a view that nature is kind and the best will happen. An optimist following the maximax concept selects the alternative possessing the largest outcome in the payoff table; in our example that is A1—major expansion with an outcome of 12. Between maximin and maximax lie many shades of enthusiasm. In the Hurwicz criterion, the position between the extremes is denoted by alpha ($\alpha$), the coefficient of optimism. After selecting an $\alpha$ value, the highest outcome for each alternative is multiplied by $\alpha$, the lowest by $1 - \alpha$, and the resulting two products are added to obtain a rating for each alternative. As applied to our example using $\alpha = 0.5$, half way between optimism and pessimism, we get the following values for the three expansion alternatives:

| ALTERNATIVE | HIGHEST OUTCOME TIMES $\alpha = 0.5$ | LOWEST OUTCOME TIMES $\alpha = 0.5$ | SUM | |
|---|---|---|---|---|
| A1 | $12 \times 0.5 = 6$ | $-15 \times 0.5 = -7.5$ | $-1.5$ | equal preference for A2 and A3 indicated by $\alpha = 0.5$ |
| A2 | $6 \times 0.5 = 3$ | $-3 \times 0.5 = -1.5$ | 1.5 ← | |
| A3 | $3 \times 0.5 = 1.5$ | $0 \times 0.5 = 0$ | 1.5 ← | |

The degrees of optimism at which the preference switches from one alternative to another is shown in Figure 13-12.

### Principle of Regret (Savage Criterion)

The fourth principle utilizes a concept similar to the opportunity costs we encountered in previous chapters. The opportunity cost of an outcome is measured by the difference between the payoff actually received and the payoff that could have been received if the decision maker had known in advance which state of nature was going to occur. Specifically, *regret* is the absolute difference between the numbers in one column of a payoff table and the highest number in that column. For instance, in our example the largest number in column N1 is 12, which makes the regret for the alternatives equal to 12 − 12 = 0 for A1, 12 − 6 = 6 for A2, and 12 − 3 = 9 for A3. A rational decision maker tries to minimize his regret by choosing the alternative which has the least regret; he wants to minimize his maximum regret—minimax. The resulting preference as indicated in Figure 13-13 tends to be on the conservative side.

| | N1 | N2 | N3 | Maximum regret | |
|---|---|---|---|---|---|
| A1 | 0 | 0 | 15 | 15 | |
| A2 | 6 | 3 | 3 | 6 | ← minimum of the maximum regrets |
| A3 | 9 | 4 | 0 | 9 | |

*Fig. 13-13. "Regret" table calculated from the data in Fig. 13-9 by subtracting each column's values from the largest number in that column. The criterion to minimize regret suggests a preference for A2 (limited expansion). Selection of A2 means the organization's regret for selecting the wrong alternative cannot exceed 6 ($600,000), no matter what state of nature prevails.*

## DECIDING TO DECIDE

No single decision rule has unanimous support from practitioners or theorists. Too many factors are involved. Throughout this book we have examined the

ARE YOU STILL HAVING TROUBLE MAKING DECISIONS?
WELL . . . YES AND NO.

*Fig. 13-14.*

inputs to decision situations. We have also considered may techniques to handle special situations and general procedures to encourage more thorough evaluation of all significant decisions. The selection of specific decision tools depends on personal choice, management policy, and the resources available to assist the decision process. Policy and resources are a function of time and place. Personal choice relies on an individual knowing what tools are available and understanding their use. The graphic art of management contributes to better decisions, and better decision making is fundamental to the art of management.

## REFERENCE

1. Decision trees, sensitivity analysis, utility of outcomes, and other extensions are described in James L. Riggs' *Economic Decision Models for Engineers and Managers,* McGraw-Hill Book Company, New York, 1968.

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